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THESIS

AN IMPROVED SEARCH AND SCAN TECHNIQUE
FOR SHORT RANGE AIR DEFENSE CREWMEN

by

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June 1983

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(20. ABSTRACT Continued)

effectiveness of each technique. Analysis of experimental data suggests that one pattern is significantly more effective than other patterns currently in use. Recommendations are also made to improve SHORAD visual search effectiveness by adopting specific training programs.

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An Improved Search and Scan Technique for Short Range Air Defense Crewmen

by

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ABSTRACT

U.S. Army Short Range Air Defense (SHORAD) systems require visual detection of threatening aircraft prior to initiating engagement procedures. This thesis evaluates alternative visual search techniques which employ scan patterns derived from an understanding of SHORAD capabilities, the tactical air threat, and human visual search phenomena. An experiment was conducted to determine the overall effectiveness of each technique. Analysis of experimental data suggests that one pattern is significantly more effective than other patterns currently in use. Recommendations are also made to improve SHORAD visual search effectiveness by adopting specific training programs.

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I. INTRODUCTION

A. GENERAL

The defense of ground combat and support units against aerial attack is dependent upon the capabilities of a wide variety of weapons and weapon systems used by the various services. U.S. Army weapon systems can be classified into two general categories:

1. High to Medium Altitude Air Defense (HIMAD)--These "machine ascendant" systems consist of sophisticated radars, computers, and displays that enable detection, identification, and engagement functions to be performed electronically allowing for automation of much of the fire control problem. Current HIMAD systems include NIKE-HERCULES, Improved HAWK, and PATRIOT, which is now in full-scale production. Both HAWK and PATRIOT have a limited long range, low altitude capability as well.

2. Short Range Air Defense (SHORAD)--These weapons are designed to provide low altitude close-in air defense coverage for combat maneuver forces in the forward battle area and other critical assets located both in the forward and rear areas. Such systems can be defined as "man ascendant" since detection and identification of targets are performed visually and the decision to fire is made by crewmembers. Additionally, the target engagement process requires a high degree of operator skill to insure effective man-machine

interaction. Currently fielded SHORAD systems include VULCAN, CHAPARRAL, REDEYE, and STINGER. The recently developed DIVAD Gun is also scheduled for near-term deployment.

B. DISCUSSION OF THE PROBLEM

The extended range detection capability provided by the powerful acquisition radars in HIMAD systems enable much longer response times, when compared with SHORAD systems, for target evaluation and engagement. This extended response time provided by the current HIMAD detection capability, when coupled with the high degree of automation inherent in the fire control process, appears to provide sufficient reaction time to successfully engage potential threat aircraft. However, SHORAD systems, which rely upon both visual detection and visual aircraft recognition by crewmembers, are severely limited in detection capability. Depending upon existing weapons crew visual capabilities, target factors, and atmospheric conditions, field tests have shown that detection ranges will rarely exceed the SHORAD system engagement envelope by more than a few kilometers. It will often be likely that SHORAD crews, after detecting a target, will be unable to identify and complete their weapon system engagement sequence before the target maneuvers out of the engagement envelope. Consequently, SHORAD system response times are severely limited as a result of the visual detection and identification requirements. Additionally, their relatively

small engagement envelopes necessitate rapid vew and man-machine reactions in order to successfully complete the engagement sequence. The relationships between reaction requirements for SHORAD and HIMAD systems and their corresponding capabilities are graphically presented in Figure 1. SHORAD detection limitations are further exacerbated when considering enemy air tactics that such units are likely to encounter. HIMAD systems will predictably force enemy aircraft into low level attack profiles in an effort to evade or delay detection by remaining under radar coverage. Consequently, enemy air tactics, such as nap-of-the-earth (NOE) and terrain following, increase the difficulty of radar detection by HIMAD systems and further demonstrate the criticality of early visual detection by SHORAD units.

SYSTEM TOTAL REACTION TIME		DETECTION RANGE: SHORT (VISUAL)	DETECTION RANGE: LONG (RADAR)
	FAST	ACCEPTABLE	EXELLENT (HIMAD)
	SLOW	NOT ACCEPTABLE (SHORAD)	ACCEPTABLE

Figure 1. HIMAD/SHORAD System Reaction Capability

C. PURPOSE

Target detection is the first step in any air defense weapon system engagement sequence. Increasing the range at which detection occurs will provide additional time for target identification and evaluation resulting in improved overall SHORAD effectiveness. Improved effectiveness can be attributed to:

- Increased available time, yielding additional time for target identification (friendly or hostile) and evaluation (engage or not), and
- Greater probability or successfully completing entire engagement process due to sufficient response time for weapon system and crew reaction.

Clearly the development and implementation of an effective search technique which increases the range at which target detection occurs will result in greater available time for weapon system response and crew reaction thereby contributing to improved overall SHORAD effectiveness.

Although extensive research has been conducted in the broad field of human visual detection, very little effort has been designed to investigate the effectiveness of various search patterns on detection [Ref. 1: pp. 127-129 and Ref. 2: p. 2]. Consequently the purpose of this thesis is to analyze those factors which significantly impact upon SHORAD visual detection in an effort to determine whether or not such factors may suggest an improved search technique. Factors

identified as relevant to SHORAD visual detection include:

- SHORAD weapon system capabilities and limitations,
- Air threat characteristics, and
- Human visual search and detection phenomena.

If such an analysis of search and scan techniques reveals an alternative to the two techniques currently recommended in field manuals, an experiment will be performed to determine whether or not the hypothesized technique is, in fact, more effective than techniques currently recommended.

D. OBJECTIVES

The principle objectives of this thesis include the following:

1. Derive a theoretically credible ground-to-air search technique for ground observers in general, and SHORAD weapons crews in particular,
2. Design and conduct a field experiment to test this hypothesized alternative against current search techniques to determine which yields the most effective results, and
3. Examine current training procedures to determine where improvements, if any, may be made to increase SHORAD visual search effectiveness.

II. FACTORS BEARING ON THE PROBLEM

A. GENERAL DISCUSSION

Three significant factors which together interact to determine the effectiveness of a search technique are the following:

1. Weapon system engagement capabilities and limitations,
2. Threat characteristics, and
3. Visual search and detection phenomena.

Generally, search effort should be expended in areas that are most likely to produce targets that are, or will soon be, within the SHORAD system's engagement envelope. Stated otherwise, search effort expended on high altitude targets is essentially wasted since SHORAD systems have limited effective ranges. Likewise, it is not productive to search areas where targets are not likely to be located. Hence, an understanding of the threat should prove beneficial in the development of an optimal search technique. Finally, human visual search effectiveness is a function of target parameters, the attenuating effects of atmospheric and environmental conditions, and the general acuity of the individual human visual system. This chapter analyzes those aspects of the three significant factors listed above which are pertinent to the SHORAD visual search problem. Hopefully such analysis will enable derivation of an intuitively appealing and theoretically plausible search technique which can be compared to currently recommended techniques.

B. CURRENT SEARCH AND SCAN TECHNIQUES

The current visual search and scan techniques recommended for use by SHORAD weapon system crews are specified in Department of the Army Field Manual 44-23-1, REDEYE Operations and Training, and Field Manual 44-18-1, STINGER Operations and Training. Both manuals suggest two patterns for effective ground-to-air search [Ref. 3: pp. 3-7, 3-8 and Ref. 4: pp. 4-1 through 4-7]:

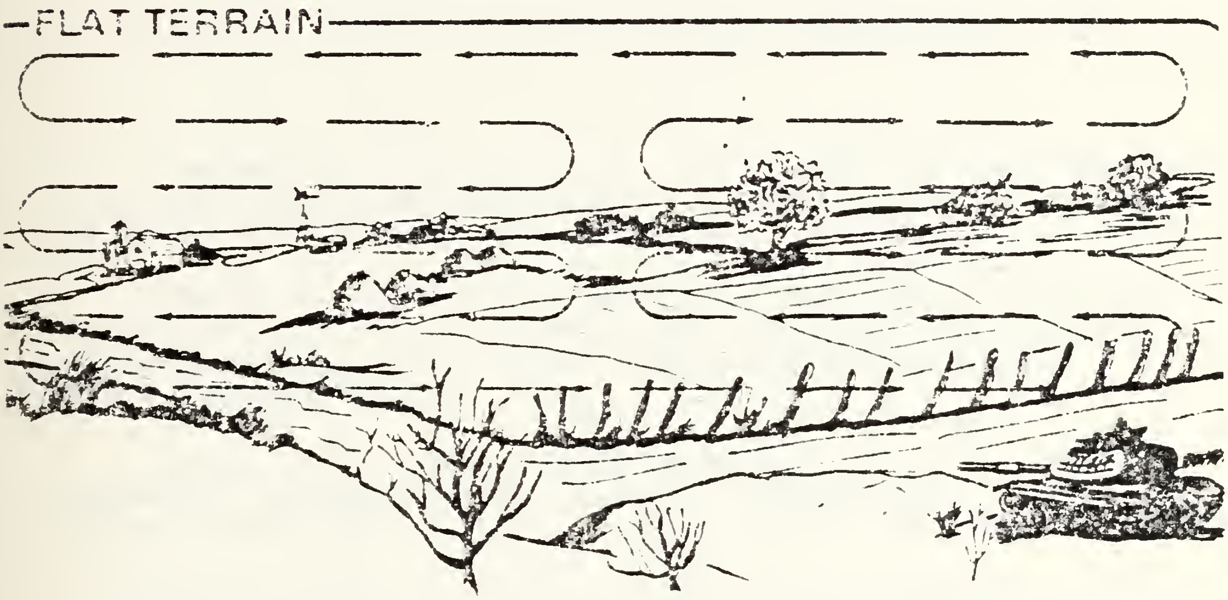

Figure 2. Lateral Search Pattern [Ref. 3, p. 3-7]

1. Lateral Search
2. Vertical Search

The field manuals also provide some additional suggestions to the SHORAD crewman:

Figure 3. Vertical Search Pattern [Ref. 3: p. 3-8]

Frequently focus his eyes on a distant object, such as a cloud or terrain feature. Otherwise, the eyes tend to relax and distant objects become blurred.

Search the area near the sun by placing his extended thumb over the sphere of the sun. Looking into the sun, without shielding it, causes the eyes to be blinded for a few seconds.

Squint, if he has trouble focusing at long ranges. Squinting compresses the eyeball, changing its focal length, and makes distant objects come into focus.

Keep his eyes on the aircraft once he sees it. If he has to look away from it, he notes the direction of the aircraft and moves his eyes away from it when the aircraft is near some object, like a cloud or a terrain feature, that will guide his eyes back to it. [Ref. 3: p. 3-7]

Observers are also encouraged to look for such things as:

Sun reflection from aircraft canopies or cockpit windows.

Blade flash from rotating helicopter blades.

Smoke or vapor trails from jet aircraft and missiles or rockets fired from aircraft.

Dust or excessive movement of tree tops and bushes in a particular area.

Noise from helicopter blades or from jets breaking the sound barrier. [Ref. 3: p. 3-8]

These search and scan patterns were originally developed in the early 1960s when the current family of SHORAD weapons were being acquired and initially fielded. The lateral search technique is an adaptation of search patterns specified in U.S. Navy Bureau of Personnel (BUPERS) Manuals which were originally used by observers on board ships in the Pacific Theater during World War II to detect aerial and especially kamikaze attacks. The vertical search was offered as an additional technique intended specifically for hilly and mountainous terrain. Its selection was not founded upon any particular empirical or theoretical results known at the time, but rather represented the best collective judgement of responsible personnel serving in the proponent agency. Especially noteworthy is the fact that no specific threat was assumed during the formulation of these two search and scan techniques.* These techniques, which are currently in use, have remained essentially unchanged since their inception nearly two decades ago.

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*Information in this paragraph was provided to the author by Mr. O.J. Vaillancourt of the Tactics Department, U.S. Army Air Defense School, during a telephone conversation on 28 Jan 83.

C. SHORAD WEAPON SYSTEM CAPABILITIES AND LIMITATIONS

1. General

SHORAD weapon systems, which have the general mission of providing low altitude close-in air defense coverage, are normally employed in support of division and lower level (i.e., company, battalion, and brigade) maneuver and fire support units and their critical assets. Such protection is necessary to enable combat forces to retain their maneuverability and essential combat capabilities on the battlefield. SHORAD systems can generally be characterized as follows:

- Since current SHORAD systems are visually directed rather than radar directed (with the single exception of the SGT YORK Gun, which is dual capable), target engagement decisions are decentralized to the individual fire unit level in accordance with air defense doctrine. Hence target detection and identification are normally accomplished visually by SHORAD crews.
- SHORAD systems have limited maximum effective engagement ranges varying from 1.2 to 5 kilometers.
- Limited early warning may be available to SHORAD systems, although under ideal conditions, tentative target identification and approximate range and azimuth would be electronically supplied from the FAAR/TADDS and/or other early warning systems.
- SHORAD systems, previously referred to as "man-ascendant", are characterized by relatively limited automation and

require substantial amounts of manual operator tasks to be performed quickly and correctly in a short amount of time to insure successful man-machine interaction and completion of the engagement process. SHORAD crews must also perform multiple hand-off tasks between the crewmember who initially detects the target, the squad leader (or team chief) who is exclusively responsible for making the decision to fire at a target, and the gunner who physically controls and fires the weapon system. Hence, such systems require substantial operator skill during periods of high human workload and very limited reaction times.

SHORAD systems can be divided into gun systems, consisting of the VULCAN and SERGEANT YORK Guns, and missile systems, including the CHAPARRAL, REDEYE, and STINGER-guided missile systems. Detailed descriptions of specific systems are provided at Appendix A.

2. <u>SHORAD Engagement Envelopes</u>

Engagement envelopes for the various systems are developed by analyzing their respective minimum and maximum intercept boundaries. Such boundaries are dependent not only upon missile or ammunition ranges and gun/cannon elevation limits but also target characteristics, such as strength of IR source, aircraft velocity (speed and direction), and altitude. Nonetheless, "standard" engagement envelopes have been developed and are frequently used for tactical air defense design and planning purposes. Side

views of these engagement envelopes, which provide a graphical indication of each of the SHORAD weapon system engagement capabilities just described, are provided at Figure 4. Maximum effective ranges illustrated are those currently used for instruction by the Tactics and Doctrine Branch, Tactics Department, U.S. Army Air Defense School.

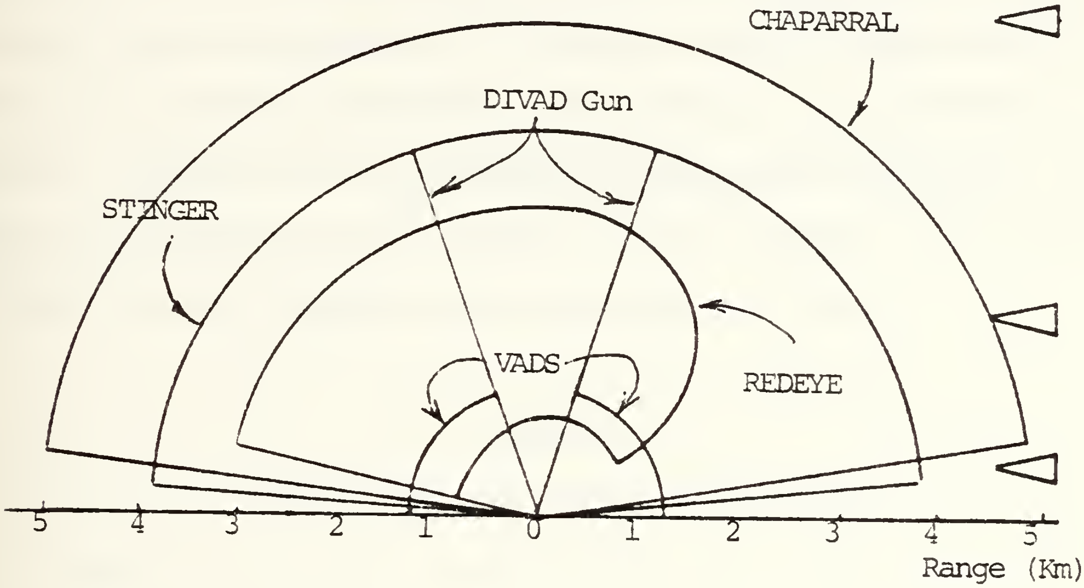


Figure 4. SHORAD Engagement Envelopes

D. THE TACTICAL AIR THREAT

As previously mentioned, a thorough knowledge of the potential air threat, in addition to the SHORAD weapons engagement capabilities and limitations just described, is necessary in order to develop an efficient and effective SHORAD visual search technique. Failure to direct the preponderance of search effort in regions where enemy

targets are most likely to be located will obviously reduce not only the range at which visual detection occurs, but even more importantly, reduce precious crew reaction time which is severely limited already. A revealing example of the consequences of such a failure occurred in the early evolutionary stages of military operations research during World War II. Morse and Kimball provide an illustrative example of the importance of properly distributing search effort using wartime data on search for off-shore submarines by anti-submarine aircraft. The analysis is presented in their classical work, Methods of Operations Research: Report No. 54, published in 1946 [Ref. 5, pp. 40-43]. Tabulated results of the problem are presented at Table I.

TABLE I

Offshore Sightings of Submarines

Region	A	B	C	D
Distance from Shore (miles)	0 to 60	60 to 120	120 to 180	180 to 240
Flying time in Region (hrs x 1000)	15.50	3.70	0.60	0.17
Contacts in Region	21	11	5	2
Contacts Per 1000 hrs flown	1.3	3	8	12

Examining submarine sightings by region (which seems, at first, to be a conspicuous indicator of effectiveness) reveals that more contacts were made in region A than

elsewhere. However, this factor provided illusory results to the operations officers who may have been persuaded even further to increase the proportion of flying time in region A, although nearly 100 times more flight hours were already being expended in region A than in region D. However, a comparison of the different values of sightings per 1000 hours flown immediately reveals the ineffectiveness of the search effort. Searching in region A, where three-quarters of the flying was done, is only one-tenth as effective as flying in region D, where less than 1 percent of the flying was actually done. When these facts were pointed out, flying effort was redistributed with a notable improvement in effectiveness.

Although this particular analysis concerned air-to-sea search for submarines by anti-submarine aircraft, the same general principle applies to ground-to-air search for aircraft by ground observers as well: search effort should be concentrated in regions most likely to reveal what is being searched for.

Unquestionably the most complex, capable, and potentially devastating air threat that the U.S. ground forces could conceivably face is the Soviet Air Force. The component of the Soviet Air Force that SHORAD units are most likely to encounter is the tactical air arm, Frontal Aviation (FA), which is the largest element of their air force. In addition to a large inventory of very capable high-performance fixed-wing ground attack aircraft, SHORAD units

are also faced with a rapidly expanding attack and armed helicopter fleet that now operates as a full fledged combat arm within the Soviet concept of a combined arms force. During the past decade the Soviet Air Force, in general, and Frontal Aviation, in particular, have witnessed dramatic change of monumental significance. Frontal Aviation has been radically and fundamentally altered from a defensive, air cover oriented force into a modern and powerful offensive force capable of effective and sustained ground attack operations with a wide spectrum of capabilities. The transformation, modernization, and growth of both Frontal Aviation and "Army Aviation", as the combat helicopter force has recently been designated, are outlined in significant detail in Appendix B, to which the reader is referred for a more extended discussion. Current missions and capabilities of both Frontal Aviation and Army Aviation forces can, however, be briefly described as follows:

Frontal Aviation missions--

1. Conduct independent air operations to pre-empt, by neutralization or destruction; NATO rear area nuclear facilities and command and control centers in an effort to eliminate an immediate NATO nuclear retaliation capability thereby exerting reflexive control over NATO tactical options.
2. Establish early air superiority by conducting offensive counter-air operations, emphasizing suppression and elimination of NATO radar directed SAM systems, such

as NIKE-HERCULES, HAWK, and PATRIOT, and air base attack against 2nd and 4th Allied Tactical Air Force (ATAF) airfields. The battlefield air defense mission is predominantly accomplished by Soviet mobile ground based air defense, which is integral to all command levels from front to maneuver battlaion. However, FA retains a significant air-to-air capability, including both look-down and shoot-down capabilities on recently developed fourth generation aircraft.

3. Conducting <u>offensive air support operations</u>, emphasizing both interdiction, by providing an extension to ground artillery in support of the commander's maneuver plan, and tactical air reconnaissance, by providing near real-time intelligence input for both immediate evaluation as well as inclusion into the Soviet automated troop control system. FA also provides air support for "independent" forces, such as operational maneuver groups, airborne units, and air assault forces, operating autonomously on an extended battlefield.

Frontal Aviation capabilities--

1. FA consists of potent, long range, tactical aircraft optimized for ground attack and capable of conducting a large scale air attack against NATO air defenses, airfields, control systems, and nuclear facilities.
2. Current third generation aircraft are capable of carrying large conventional and/or nuclear payloads,

including tactical air-to-surface missiles (TASM) with increasingly longer stand-off ranges, over long distances at high speed and extremely low altitude (well below 500 feet), thus avoiding detection by ground based radar systems, and delivering payloads with great accuracy.

3. Aircraft are capable of high sortie rates and short turn around times, due to short take-off and landing (STOL) design features, rugged landing gear, and rapid refueling and rearming thus permitting forward basing and quick responsiveness to air support requests.

Combat Helicopter missions--

1. Ground support operations in direct support of the ground tactical commander, including:
   - anti-armor operations
   - anti-helicopter operations
   - "on call" close air support (CAS) to conduct preparatory fires, repel enemy counterattacks, eliminate pockets of resistance, and engage targets of opportunity
   - troop transport across obstacles
   - security force operations, both beyond the line of contact and on exposed flanks
2. Air assault and transport operations, conducting independent operations to seize critical objectives in the enemy rear.

Combat Helicopter capabilities--

1. The MI-24 HIND assists in supporting the high speed offensive by virtue of its mobility, lethality, and reduced vulnerability. It can accurately deliver tremendous firepower and is regarded as a high speed, nap-of-the earth (NOE) "tank".
2. Navigation and fire control systems permit NOE, all-weather flight and a capability to "pop-up" and launch anti-tank guided missiles (ATGM) and rockets from long stand-off ranges, thus delaying and often completely avoiding detection altogether.
3. The massive combined MI-24/MI-8 force permits multiple large air assault forces to be transported and supported well into enemy rear areas to disrupt and/or seize critical objectives.

The following major points summarize the transformation of FA units into an offensive air support force, and the current status of the modernization effort implemented during the past decade:

- Soviet FA has been transformed frcm a numerically inferior defense oriented fighter/interceptor force consisting of limited range, low payload, day dighters into a numerically superior force of potent, long range, tactical aircraft capable of "air attack in all its forms" with an increasing capability to operate in adverse weather.

- Employment doctrine is aimed at achieving air supremacy through conventional pre-emptive air operations including a massive coordinated air attack against NATO air defenses, airfields, control centers, and mobile as well as fixed nuclear capable targets.
- An extensive and simultaneous buildup of mobile ground based SAM systems has relieved FA of its air defense role and enabled it to concentrate on optimizing for offensive air support (OAS) operations.
- Due to their mobility, large load capacity, powerful armament, lower vulnerability, better responsiveness, and longer loiter capability, combat helicopters now perform the CAS mission, thus releasing fixed wing FA for battlefield interdiction where it can be better utilized as an extension of artillery on an extended battlefield.
- Recently, helicopter forces have been detached from FA Tactical Air Armies and subsequently reorganized into Army Aviation units as an integral air arm consisting of combat helicopters functioning as full fledged members of a combined arms force conducting high speed offensive operations.
- Tactics to accomplish OAS operations all demand low level flight to avoid radar detection, with fixed wing ground attack aircraft concentrating on high speed, low level penetrations to conduct interdiction missions,

and rotary wing emphasizing NOE navigation and short exposure "pop-up" techniques for ordnance delivery.

Of particular significance to SHORAD units, as well as air defense in general, is this last point which emphasizes the Soviet capability to fly very low. Clearly their intentions are to make predominant use of low level flight techniques for most of the interdiction on low-level flight, especially recognizing the advantages of terrain masking obtained by terrain avoidance and nap-of-the-earth tactics, is clearly evident in their training literature. Such training emphasis appears to be validated by our own recent Red Flag exercises which indicate that helicopters using "pop-up" attack techniques are detected less than 40 percent of the time [Ref. 6: p. 54]. Estimates of the distribution of the threat, as a function of altitude, are tabulated in Table II and presented graphically at Figure 5. These estimates of the current and projected threat are presently being used for studies and analysis by the Directorate of Combat Developments, U.S. Army Air Defense School, and were recently validated by Training and Doctrine Command (TRADOC).

With this understanding of the location of the threat, which rapidly diminishes with increasing altitude, the previously derived need to search in areas most likely to reveal targets strongly suggests the following:

An effective search technique for ground observers requires the preponderance of search effort to be concentrated

TABLE II

Target Density as a Function of Altitude

Target Density by Altitude Bands

Altitude (meters)	0-500	501-5000	5001-10,000	10,001-20,000
% of Aircraft	81	7	6	6

Cumulative Density of Targets

Altitude (meters)	$\leq$ 500	$\leq$ 5000	$\leq$ 10,000	$\leq$ 20,000
% of Aircraft	81	88	94	100

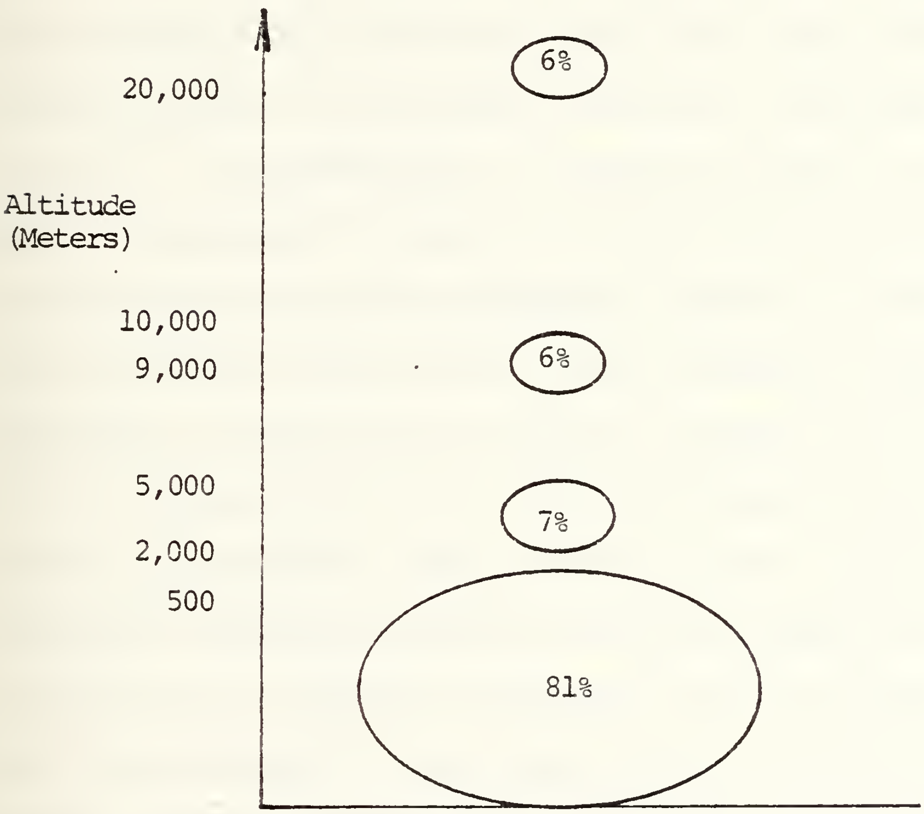


Figure 5. Graphical Representation of Target Density (NOTE: Altitude Axis is not To Scale)

at altitudes well below 5000 meters where nearly 90 percent of the targets are expected to be operating.

E. VISUAL SEARCH AND DETECTION FACTORS

1. General Discussion

Extensive research has been conducted to determine and measure the functions, capabilities, and limitations of the human visual system. In a search task it has been found that visual detection is dependent upon a variety of factors which interact synergistically to determine overall visual quality in any particular situation. Such factors can generally be classified into three broad categories: target factors, environmental factors, and human visual factors. The probability of actually seeing a target is usually expressed in terms of various basic detection thresholds which have been examined in numerous laboratory and some field experiments. Such thresholds have been developed for many of the various effects which are relevant to the ground-to-air visual detection task. Characteristics and phenomena which appear to most significantly influence aircraft detection by ground observers are listed in Table III. Although extensive basic laboratory research has been conducted on the human visual system relatively little applied research or field testing has been conducted on military related search tasks. With the exception of a series of tests performed for the U.S. Army Research Institute (ARI) in the 1960s and early '70s, very little research

TABLE III

Human Visual Search Categories and Factors

TARGET FACTORS	ENVIRONMENTAL FACTORS	HUMAN VISUAL FACTORS
Size & Shape	Background	Eye Structure
Luminance	Luminance	Occulomotor Functions
Brightness	Color	Search Area
Color	Structure	Target Motion
Special Effects	Atmospherics	Accommodation
Exhaust Plumes	Attenuation	Effects of:
Rotor Flicker	Turbulence	Stress
Glint	Glare	Anxiety
Dust		

has been conducted on visual ground-to-air detection and essentially none has been conducted to determine the effects of various search patterns upon detection. This lack of such empirical knowledge was most recently noted in a 1980 report prepared by the Virginia Polytechnic Institute's Department of Industrial Engineering and Operations Research which provides one of the most comprehensive summaries available on human visual target acquisition. The report concludes with a suggested research program which strongly recommends initiation of applied research on search techniques and training [Ref. 1: pp. 127-129]. Despite the lack of such empirical search pattern evidence other significant factors relevant to the ground-to-air detection have been isolated and measured in laboratory and field tests. The results of such research are summarized below. A more

detailed discussion of such factors along with supporting documentation can be found in Appendix C.

2. Target Factors

The predominate target attributes which determine detection in a uniformly unstructured field are target size and contrast.

As might be expected, if the size of an object is increased, other conditions being held constant, it becomes easier to see. Apparent target size, when viewed from the observer, is clearly a function of slant range and presented target area, or aspect. A series of tests conducted in the early 1960s by the U.S. Army Human Engineering Laboratory (HEL) and Human Resources Research Organization (HumRRO) indicate that:

- Target size definitely effects range of detection; larger targets are detectable at longer ranges, and
- Detection range increases as the aircraft aspect moves from head on to tangential, due to a commensurate increase in apparent target area.

Shape appears to be an unimportant factor in determining detection thresholds for small targets, although one study indicates that detection probability is reduced as the ratio of ratio length to width increases.

The second critical target property which determines detection is target luminance. Target and background luminance, or brightness, together determine the luminosity contrast (CL) and is expressed as follows:

$$CL = |B-B'|/B'$$

where B is target luminance and B' is background luminance. Hence target luminance is the property which largely determines contrast and influences detectability. Note that whether or not the target is brighter or darker than the surrounding background does not affect contrast, although some evidence suggests that targets brighter than their backgrounds are slightly less detectable than targets of the same contrast but which are darker than their background. Color, or chromaticity, contrast has also been found to significantly influence target detection with yellow/orange and blue/green targets are readily discernible than extreme blue and red on a neutral background. Chromaticity contrast (CC) is defined as:

$$CC = |C-C'|/C'$$

where C is target chromaticity (wavelength) and C' background chromaticity. It has been suggested that total contrast can then be determined as the root mean square of luminosity and chromaticity contrast:

$$CT = \sqrt{CL^2 + CC^2}$$

Two other target characteristics, speed and altitude, also affect target detection. Both will be discussed as components of other categories since target relative motion

influences detectability through complex physiological functions whereas target altitude, in addition to determining slant range, specifies atmospheric attenuating conditions which are discussed in the next section.

Often special effects created by the target, rather than the target itself, generate the initial reaction to focus search in a particular area. Such effects include:

- Exhaust plumes from jet aircraft,
- Canopy sunlight reflections creating glint, and
- Helicopter rotor flicker and dust caused by rotor downwash.

The previously cited tests conducted by HumRRO also concluded that increased density of exhaust fumes resulted in increased range of detection for low altitude jet aircraft. Also noted were increased detection ranges for crossing targets relative to head-on targets, since total exhaust area visible to the observer is larger for crossing targets. A series of tests conducted by the U.S. Army Combat Developments Experimentation Command (CDEC) during the mid-1970s revealed that ground observers searching for helicopters using "pop-up" tactics reported rotor flicker to be the primary detection cue. Helicopters using other tactics were detected as they crossed the field of view for a variety of other reasons, for which dust, rotor-flicker, and glint contributed .5%, 7.5%, and 8.9% as the primary detection cues.

3. Environmental Factors

In most cases the ground-to-air search task is significantly and often decisively affected by surrounding conditions of visibility. Background luminance and structure (or lack thereof), contribute to the difficulty of target detection. Particularly significant are the attenuating effects of atmospheric conditions (weather) and, especially at low altitudes, turbulence.

As previously discussed, background luminance (B') and target luminance (B) determine the contrast (CL) which is widely regarded as the most critical objective factor in target acquisition. Hence target contrast is not a simple property determined solely by the target itself but must be specified by local background luminance as well. Reducing background luminance results in progressively greater difficulty seeing any particular object. For example, tests have shown a reduction in the detection range when ground observers are searching for aircraft at the onset of twilight, due to gradually diminishing background luminance. Background chromaticity (C') also influences detection ranges as tests have shown conclusively that, at equal luminosities, there exists a significant difference between grey and blue sky backgrounds upon detection range.

Structure, or the degree of "clutter" or "noise" in the background, also influences target detection. An unstructured, or purely "empty field", which is characterized

by a background of uniformly constant luminance containing few or no readily discernible objects (such as clouds or trees) creates a physiological phenomenon referred to as "empty field myopia". Such a condition, which will be discussed further in the section on visual factors, makes target detection extremely difficult. Although background structure appears to assist in target detection by inducing some type of systematic search pattern, excessive background structure creates an overabundance of visual clutter and inhibits target discrimination, or the ability to pick out and distinguish targets from the surrounding background.

Although contrast is a predominant factor in target acquisition for long-range search problems the intervening atmosphere normally diminishes target properties and reduces the inherent contrast. The two phenomena which account for this effect are atmospheric attenuation and atmospheric turbulence. Attenuation reduces target contrast transmittance due to the absorption and scattering of light from particles and moisture in the intervening media. Obviously weather effects, measured as meteorological visibility, contribute to atmospheric turbidity as do effects such as smoke, dust, haze, and other obscurants. A thorough investigation of atmospheric attenuation has revealed that contrast is an exponentially decreasing function of range and can be defined as:

$$C_r = C_o e^{-\sigma_e R}$$

$$\sigma_e \text{ (extinction coefficient)} = 3.912/V$$

where C_o is inherent target contrast, R is the range of the target from the observer, V is the meteorological sighting range based on atmospheric conditions (it is defined as that range for which the contrast transmittance of the atmosphere is 2%), and C_r is apparent target contrast at the observer's position. Hence light reflected or generated by the target and its background forms a predictable retinal image contrast after having been attenuated by the intervening atmosphere. The second optical effect which distorts target properties is atmospheric turbulence, or "shimmering", which is due to local refraction by the atmosphere. The two major sources of turbulence are wind shear and convective heating from the ground. For targets close to the ground on hot days the effects of heat convection can be extremely serious and cause targets, which would otherwise be clearly visible, to disappear altogether. The degrading effects of both attenuation and turbulence cause effective slant path viewing range to decrease as a function of decreasing target altitude. This especially affects targets near the horizon due to a combination of both the near-surface convection problem and the usual tendency of the extinction coefficient (σ_e) to reduce with height. This phenomenon is graphically presented in Figure 6. For example, a target at 10 kilometers slant range may be clearly visible at an altitude of 5 kilometers but invisible if it

is hovering just above the ground. Additionally, field studies have shown that targets approaching at higher altitudes are detected at longer ranges than those approaching at lower altitudes.

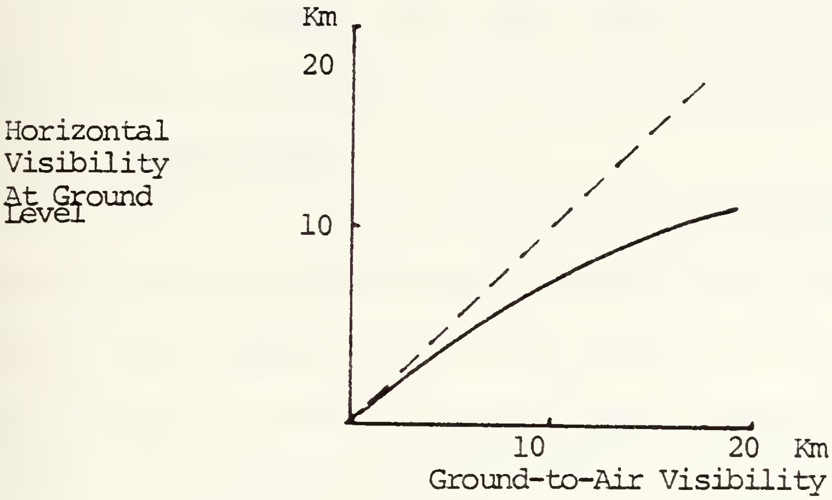


Figure 6. Atmospheric Effects on a Target at 100-200 Meters [Ref. 13: App. C, p. 331]

Another environmental factor which can inhibit target detection is glare within the visual field. Sources of glare include direct rays from the sun, or light reflected from bodies of water or very light desert-type terrain. Glare will significantly inhibit visual effectiveness if the source of glare is within the visual field and substantially greater in luminance than the level to which the eyes have been adapted. Laboratory studies indicate that the effects of glare become worse as the glare source moves closer to the line of sight. For example, one study shows that a glare source 50% greater than that to which the eyes

have been adapted gradually reduces visual effectiveness from 58% when the glare source is positioned 40 degrees from the eye-test object line of sight to 16% when the source is 5 degrees from line of sight. Obviously a potentially significant glare source for the ground-to-air search task is the sun. Studies have shown that an increase in sun-target angle increases the range of target detection.

4. Human Vision

The third and final category of factors which impact upon the ground-to-air search task includes those human visual capabilities which enable an observer to actually see a target. Such an analysis must include a discussion of both the physical and the physiological properties of the visual system which together contribute to determine human visual capabilities in the ground-to-air search task.

A diagram of the physical structure of the eye reveals that the retina, upon which an image is focused, consists of two types of photoreceptors, referred to as rods and cones due to their shapes (see Figure 7). Cones, of which there are a number of different types with varying spectral sensitivity, provide the basis for color vision and are located almost exclusively near the fovea, a very small circular region on the rear retinal wall. Cone vision, usually referred to as photopic or foveal vision, provides the facility for critical vision when focused upon an object. The second type of photoreceptors, rods, are used for low-light, or scotopic, vision. They are more sensitive,

although they only provide for one spectral sensitivity, and are located outside the fovea throughout the remaining retinal wall. Rods also provide peripheral vision for objects which can subsequently be acquired, through eye movement, by the foveal cone receptors for more detailed perception. The spatial distribution of rods and cones throughout the retina is shown in Figure 8. The photoreceptors are connected to the optic nerve, which transmits visual data to the brain, by a series of interconnecting neural networks.

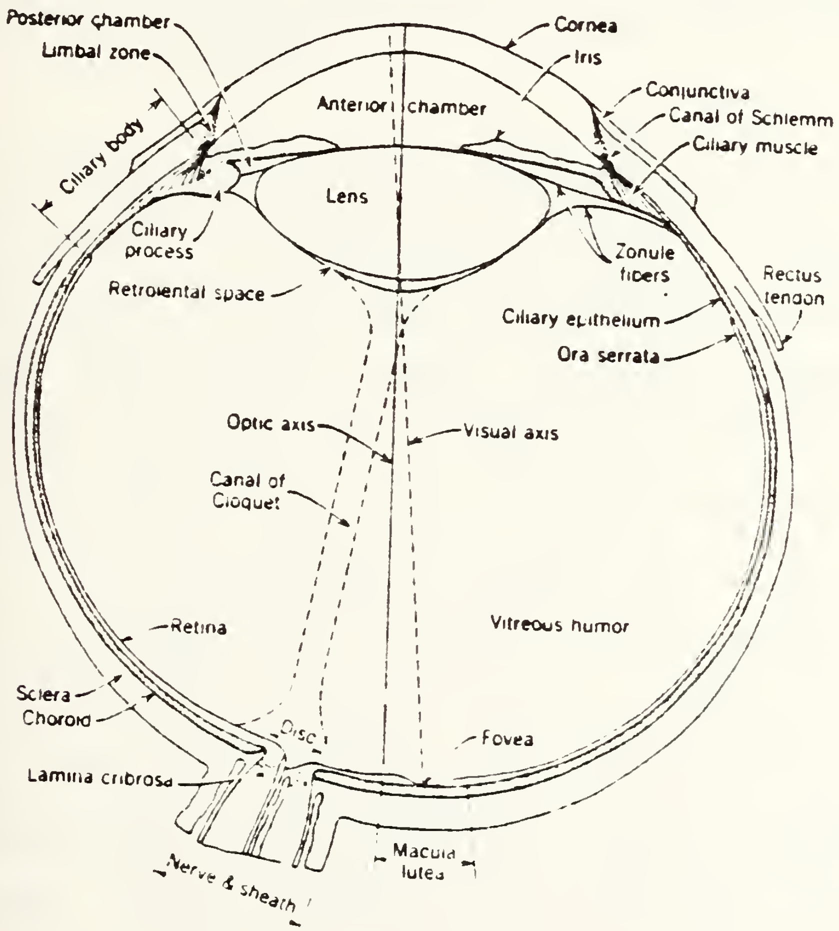


Figure 7. Cross Section of the Human Eye

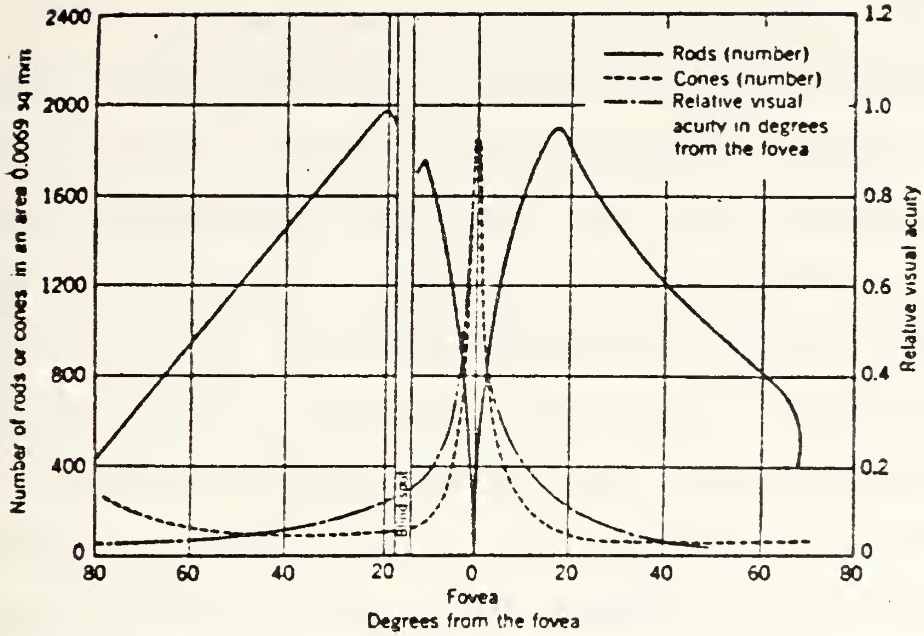


Figure 8. Distribution of Rods and Cones in the Retina

During normal vision the eyeball is in a continual state of motion. Normally the eye does not fixate upon a specific point for more than half a second. The rapid movement of the eyeball between fixations is referred to as saccadic motion. Studies have shown that, for a search task, up to 15% of the time is accounted for by saccadic motion. It is also generally agreed that little if any visual processing occurs while the eyeball moves from one fixation point to the next. It has also been found that, as the search area increases, the duration of fixations decreases while the interfixation distance (saccadic length) increases. Thus, as search area increases, less time is available for detailed vision since fixation time is reduced

while saccadic movements become longer and larger. In addition to eye movement, visual redirection is also accomplished through head and, if necessary, body movement. The interaction of these three movements, through coordinating and compensating mechanisms, has been studied. As might be intuitively expected, refixation time from one point to another is increased whenever head and body movement occur during a saccade. This result suggests that, for a given search area, more visual information can be processed by eliminating or reducing both head and body movement as long as the target remains in the field of view.

Another important result of the early HummRO studies was the effect that search sector size had upon target detection range. Field test results indicated that very narrow search sectors (5 degrees) resulted in the maximum target detection ranges (12 kilometers under ideal conditions). However, target detection range seriously deteriorated for much larger search sectors (180-360 degrees resulted in detection ranges less than 2 kilometers). Other studies also indicate that search time varies directly with the angular range over which the subject must search. Also larger areas tend to be scanned using longer interfixation distances. However, despite this tendency, it still takes a longer period of time to search the larger area.

One of the most important detection cues in the ground-to-air search task is the perception of target motion. Often, this critical cue is provided by peripheral rather

than direct foveal vision. Although static foveal acuity diminishes rapidly as an image recedes away from the fovea along the retinal wall, peripheral acuity remains relatively great and, even in the extreme periphery, is capable of detecting motion in targets that, when still, are completely invisible. Hence, peripheral vision is extremely powerful in a search task for moving targets, even when target relative motion and contrast are small and the target is located well off the observer's direct line of sight (see Figures 9 and 10).

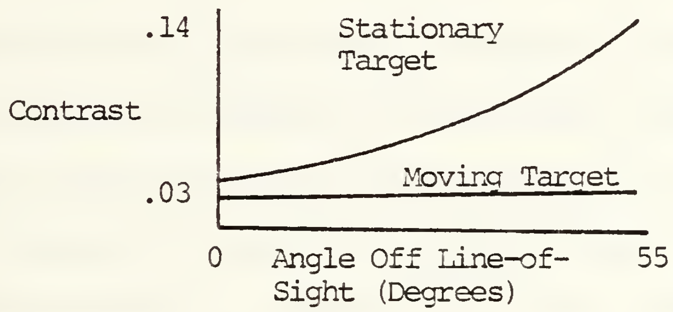


Figure 9. Peripheral Vision Effectiveness in Detecting Target Motion [Ref. 24: App. C, p. 199]

Normally objects are brought into focus, or "accommodated", through use of the ciliary muscles. However, when not in focus the eye muscles will involuntarily relax, usually within one minute, to refocus at a distance less than one meter in front of the eye. Such a condition, if it occurs during a search task, can be extremely debilitating and result in a temporary cessation of vision. Although

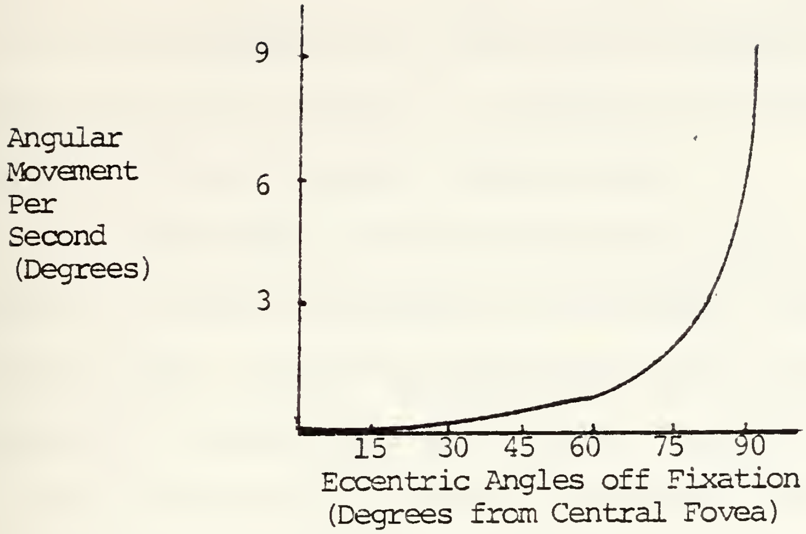


Figure 10. Motion Detection Threshold in Periphery of the Retina [Ref. 13: App. C, p. 68]

statistics are not available to indicate how frequently such a condition, referred to as "empty field myopia", may occur during ground-to-air search, it is known to be a common occurrence during air-to-air search tasks. Normally empty field myopia is induced by a structureless, uniformly plain background, such as a cloudless sky. Studies have shown that when a stimulus placed at optical infinity is located in the observer's field of view, the tendency to involuntarily refocus at near points is reduced. Such an accommodative aid has been shown to increase search performance by as much as 30%, as long as the aid is placed within 5 degrees of the line of sight. In the case of ground-to-air search, such aids may include clouds, the horizon, or any other feature located at optical infinity. Obviously,

any effective ground-to-air search technique should account for this phenomenon and incorporate procedures or optical aids which will reduce or eliminate the seriously debilitating effects of empty field myopia.

Relatively little information is available on the effects of such variables as motivation, stress, anxiety, and workload. However experimental data suggests that peripheral vision is significantly impaired under conditions of observer stress or severe vigilance tasks. Smoking also appears to reduce visual effectiveness by inhibiting accommodation.

5. Summary

Despite the lack of research specifically addressing the effectiveness of alternative search patterns, several conclusions derived from those other human visual factors discussed above should be recognized and, if possible, incorporated into a search technique for ground-to-air observers. Specifically, analysis of existing data on human visual search factors reveals that an optimal technique should possess as many of the following attributes as possible:

- Search systematically within the smallest possible sector size to reduce both lateral angular search and total search area.
- Use a search pattern that will enable detection of targets from collateral cues, such as glint and rotor flicker.

- Minimize head and body movement during the search task.
- Use direct foveal vision in areas that are likely to contain stationary targets while relying upon peripheral vision to detect moving targets.
- Use a pattern that covers the search area with small, rather than large, saccadic movements thus enabling most of the search period to consist of valuable information processing fixation time.
- Incorporate optical aids or procedures to eliminate the effects of empty field myopia by keeping the eyes focused at optical infinity.

Additionally the search procedure should be relatively simple and natural to perform so that the search pattern does not suffer discontinuities with resultant loss of effectiveness during periods of high observer stress and anxiety.

III. DERIVATION OF AN ALTERNATIVE SEARCH PATTERN

A. GENERAL

An analysis of factors bearing on the problem does suggest an alternative to the two search patterns currently recommended. This chapter addresses the logic used to formulate this alternative technique. First, a specific region of search is defined based upon the threat and SHORAD capabilities. Then a specific pattern is developed within that region considering important visual detection factors addressed in the previous chapter.

B. SEARCH REGION

The low-level and nap-of-the-earth profiles clearly suggest a need to emphasize low altitude search since it is estimated that the preponderance of threat aircraft (81%) will be operating at altitudes below 500 meters. Additionally, limitations of all SHORAD capabilities reveal an inability to effectively engage aircraft flying at altitudes greater than 5000 meters since SHORAD effective ranges are, for all systems except the CHAPARRAL, significantly less than 5000 meters. By superimposing the threat density graph upon the SHORAD engagement envelopes, the resulting pictorial representation clearly reveals the need to concentrate search effort at low altitude (see Figure 11).

This necessity is even further amplified when examining the elevation angles (above the horizon) that such profiles

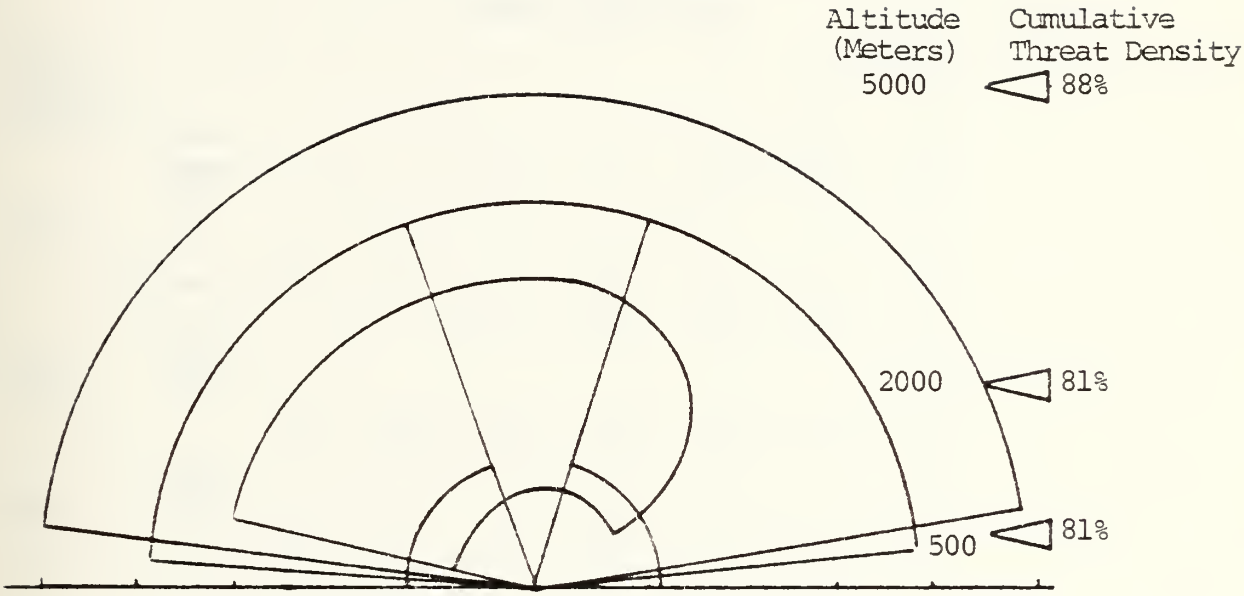
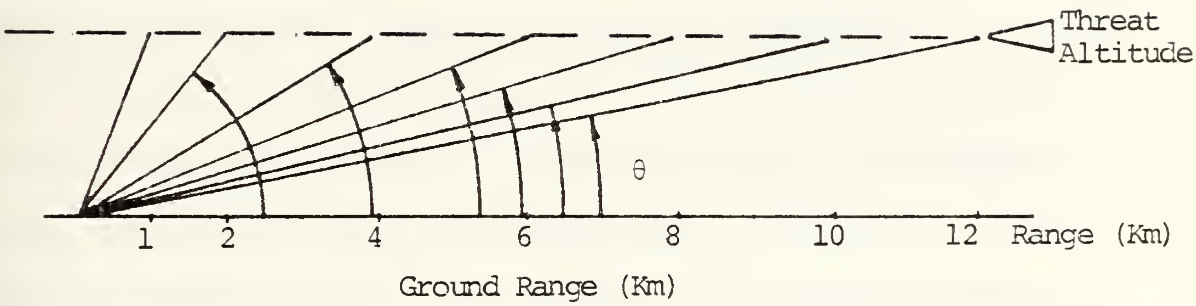


Figure 11. SHORAD Engagement Envelopes and Threat Altitudes



Threat Altitude (Meters)		1	2	4	6	8	10	12
500	Slant Range (Km)	1.1	2.1	4.0	6.0	8.0	10.0	12.0
	θ (degrees)	26.6	14.0	7.1	4.8	3.6	2.9	2.4
2000	Slant Range	2.2	2.8	4.5	6.3	8.8	10.2	12.2
	θ	63.4	45.0	26.6	18.4	14.0	11.3	9.5
5000	Slant Range	5.1	5.4	6.4	7.8	9.4	11.2	13.0
	θ	78.7	68.2	51.3	39.8	32.0	26.6	22.6

Figure 12. Target Elevation Angles for Selected Threat Altitudes

correspond to. Figure 12 illustrates the horizon-observer-target angles, or target elevation angles, which correspond to aircraft approaching at specific altitudes as viewed by the ground observer. If consideration is limited strictly to "engageable" targets, which are defined as aircraft expected to be operating exclusively within SHORAD engagement altitudes, then 91.5% of the engageable aircraft are expected to be operating at or below 500 meters with the remaining 8.5% operating between 500 and 5000 meters. Several important results are exhibited in Figure 12. In order to visually detect the overwhelming preponderance of engageable aircraft it is clearly necessary to devote search effort in a very low region near the horizon. Concentrating search effort in this region will enable the majority of targets to be detected at the maximum possible range permitted by prevailing conditions of visibility. As visibility conditions improve it clearly becomes more productive to search increasingly closer to the horizon. Under ideal viewing conditions, where maximum detection range was observed to be at approximately 10-12 kilometers for most observers according to the HummRO studies, it appears most productive to search at elevations not exceeding 3 degrees above the horizon. Devoting effort in this region will maximize detection range thereby providing the maximum possible time to complete the appropriate target engagement procedures. Even under adverse weather conditions, where

visibility may be considerably reduced, it is still essential to confine search effort at relatively low elevations, certainly not exceeding 15 degrees even for visibility conditions which have degraded as low as 2 kilometers. This apparent need to devote search effort to low elevations, which is predicated upon both the anticipated distribution of targets and weapons engagement envelopes, is also substantiated by search and detection theory which allocates search effort in a manner to maximize the overall probability of target detection [Ref. 7: pp. 239-245 and Ref. 8: pp. 5-18 and 6-1 through 6-11].

C. SEARCH PATTERN

Now that an appropriate search region has been established, the specifics of a search pattern within that region must be addressed. In this regard the most significant factors to consider are those previously discussed under the category of visual search and summarized in paragraph II.E.5 above. Within this relatively low region that comprises the area to be searched, consideration of those visual attributes provided in the summary suggests the following search pattern as an alternative:

Search back and forth within the specified sector at a constant elevation angle of no more than 5 degrees above the horizon. See Figure 13.

This constant elevation, or "horizon" search pattern appears to possess many of the attributes previously

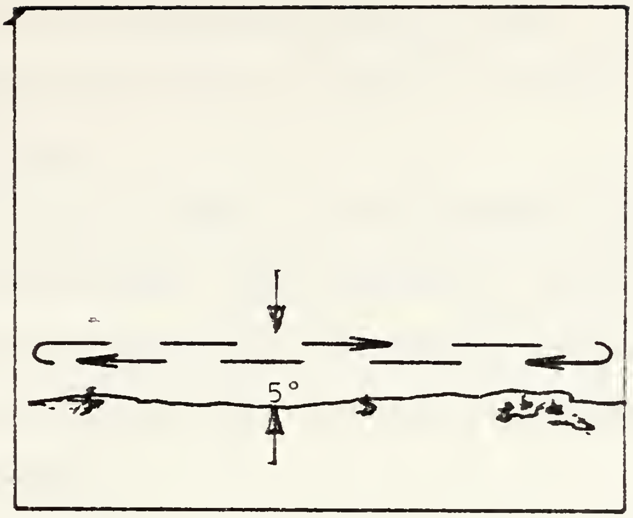


Figure 13. Horizon Search Pattern (Constant Scan No More Than 5 Degrees Above the Horizon)

identified as necessary for an optimal search technique:

- Relative to the two currently used techniques the horizon search pattern requires significantly less head movement by virtually eliminating any need for vertical head movement.

- Direct foveal vision is concentrated in areas where relatively stationary targets (such as helicopers) will be operating. Peripheral vision is used to detect moving targets at slightly higher altitudes (such as high-performance ground attack and close air support aircraft).

- Direct foveal vision is concentrated in areas close to the horizon where effective slant path visibility is significantly less than slant path visibility at higher elevation angles above the horizon.

- The horizon search enables the critical search area to be covered in a shorter amount of time than the two current

techniques. Additionally it requires fewer changes of visual direction and maximizes fixation time while reducing the length of and time spent on saccadic movement between successive fixations.

- As long as line of sight is not directed beyond 5 degrees above the horizon, the horizon can serve as a natural accommodative aid to assist in maintaining focus at optical infinity thereby eliminating the adverse effects induced by empty field myopia.

Additionally, an appealing attribute of the horizon pattern is its simplicity. This pattern forces search effort to be directed in the area most likely to reveal targets at the maximum possible detection range permitted by prevailing visibility. It also maximizes the visual power of the eye by capitalizing upon the known strength of peripheral vision to detect moving targets. Simultaneously this pattern continuously utilizes direct foveal acuity in the near horizon regions (less than 5 degrees) where targets are likely to be exhibiting less relative motion and, due to both reduced slant path visibility (caused by near-surface atmospheric effects) and increased "clutter" (which makes target discrimination more difficult), far less detectability. Realistically, such targets are most likely to be attack helicopters using "pop-up" tactics from stand-off ranges and close air support aircraft performing JAAT operations. These targets are also the most immediately threatening to SHORAD and the forces or assets they are protecting.

IV. EXPERIMENT

A. HYPOTHESIS

Although the horizon search pattern formulated in Chapter III theoretically appears to offer significant advantages over the two current search patterns, there exists no relevant field test results which might indicate its comparable effectiveness. Consequently the following general hypothesis was developed to test whether or not results derived from an experiment reinforce the theoretical supposition that the horizon search pattern is more effective than the two existing search patterns:

Hypothesis To Be Tested: "A constant elevation search technique, searching laterally within 5 degrees above the horizon (i.e., the horizon search pattern), is more effective than either the vertical or lateral techniques recommended in current field manuls".

B. MEASURES OF EFFECTIVENESS

Establishing precisely what is meant by an "effective" search is, of course, dependent upon SHORAD requirements in a combat environment. Two fundamental operational requirements are essential if SHORAD systems are to successfully engage hostile aircraft:

1. Targets must be visually detected, and
2. Detection must occur at sufficient range to permit adequate time for target identification and, if hostile,

to insure that all actions required by the weapon system's engagement sequence can be completed before the target departs the engagement envelope.

Consequently, to effectively contribute to overall SHORAD mission requirements a visual search pattern should possess the following attributes, each corresponding to the appropriate operational requirement listed above:

1. Visual target detection must occur, and
2. Detection must occur at the maximum possible range to insure that minimum SHORAD reaction requirements are met.

This second attribute is equivalent to asserting that detection occurs when a target first becomes visible, which is dependent upon prevailing conditions of visibility, or that detection occurs as soon as possible after a target becomes "detectable". These essential requirements then enable selection of relevant measures of effectiveness. Probability of target detection provides a point estimate of any particular search pattern's ability to detect targets, which is the first requirement specified above. Thus, determination of detection probability provides a specific answer to the following question:

What is the probability that an observer will detect the target?

Assuming that detection has occurred, examining the distribution of target detection times provides an indication

of how well a search pattern meets the second requirement and provides answers, in the form of probability statements, to such critical questions as:

What is the probability of detecting a target in less than 20 seconds? (20-30 seconds is approximately how long it takes a hovering attack helicopter, from its "pop-up" hover-hold position, to acquire and deliver an anti-tank guided missile [Ref. 9: p. 144, 152, 316].

How long does it take observers to detect targets? Or, queried differently, how much time, at most, is necessary for 50%, 75%, or 90% of the observers to detect a target? Specific answers to these questions, which relate directly to the previously cited SHORAD requirements, can be provided by selecting the following measures of effectiveness:

1. Detection probability, and

2. Distribution of target detection times, emphasizing the 50th, 75th, and 90th quantile values.

Examining not only the median (the 50th quantile), but also the 75th and 90th quantiles of the distribution of detection times, enables both central tendency and dispersion (or variance) information to be considered. Analysis of these statistics, when applied to experimental test results of the three competing search patterns, will then allow differences in effectiveness to be determined and provide an answer to the general hypothesis, stated in paragraph A above, which asserts that the horizon search pattern is

the most effective. Selection of these two measures thus relates search pattern effectiveness directly to SHORAD operational requirements.

C. TEST FACILITY AND SUBJECTS

The hypothesis was tested by conducting a field experiment using the REDEYE/STINGER Moving Target Simulator (MTS) operated by the 7th Infantry Division at Fort Ord, California. The MTS, a million-dollar training facility found on major U.S. Army installations, was designed and constructed in the early 1970s as a realistic, cost-effective training aid (relative to live missile firings) for MANPADS crews. The MTS consists of:

- An administrative and technical support office,
- A classroom used for lecture-type instruction such as weapons engagement procedures and visual aircraft recognition (VACR) training, and
- The simulator, where target engagement training is conducted.

The simulator consists of a large 40-foot diameter quadrasphere, modified film projectors, and two crew training stations from which MANPADS gunners, using the tracking head trainer (THT), which is an inert missile with functional infrared (IR) detection and guidance sections, track and engage aircraft displayed on the screen by a film projector. See Figure 14. Numerous film reels have been developed that depict various types of aircraft on specific combat missions

(e.g., reconnaissance, ground attack, and cargo transport). Typically, the aircraft will be projected onto the screen, maneuver toward the gunner, either head-on or slightly off-set, bank and turn presenting the gunner with various aspects to aid in VACR, and finally retreat. Stereophonic sound simulating aircraft noise is provided as an auditory cue to enhance realism. Although the target is visually detected and tracked by the gunner, the THT upon activation, will search, acquire, and lock-on to an IR "dot" that is super-imposed on the aircraft by a second projector. This IR dot is generated independently by passing white light through an IR filter. The dot can be separately controlled although it is normally slaved to the aircraft projector during training sessions.

The experiment was conducted using active duty air defense personnel assigned to the 1st Battalion, 51st Air Defense Artillery, 7th Infantry Division, stationed at Ft. Ord. Twenty-eight personnel from each of the three SHORAD military occupational specialties (MOS), including REDEYE (16S), VULCAN (16R), and CHAPARRAL (16P), were randomly selected from the four line batteries to participate in the experiment. Testing was conducted in the MTS simulator during the period Jan-Apr 1983. Specific test dates for each MOS are provided at Table IV. Table V portrays test personnel data, including rank structure, age, and experience. Noteworthy is the fact that the frequency of

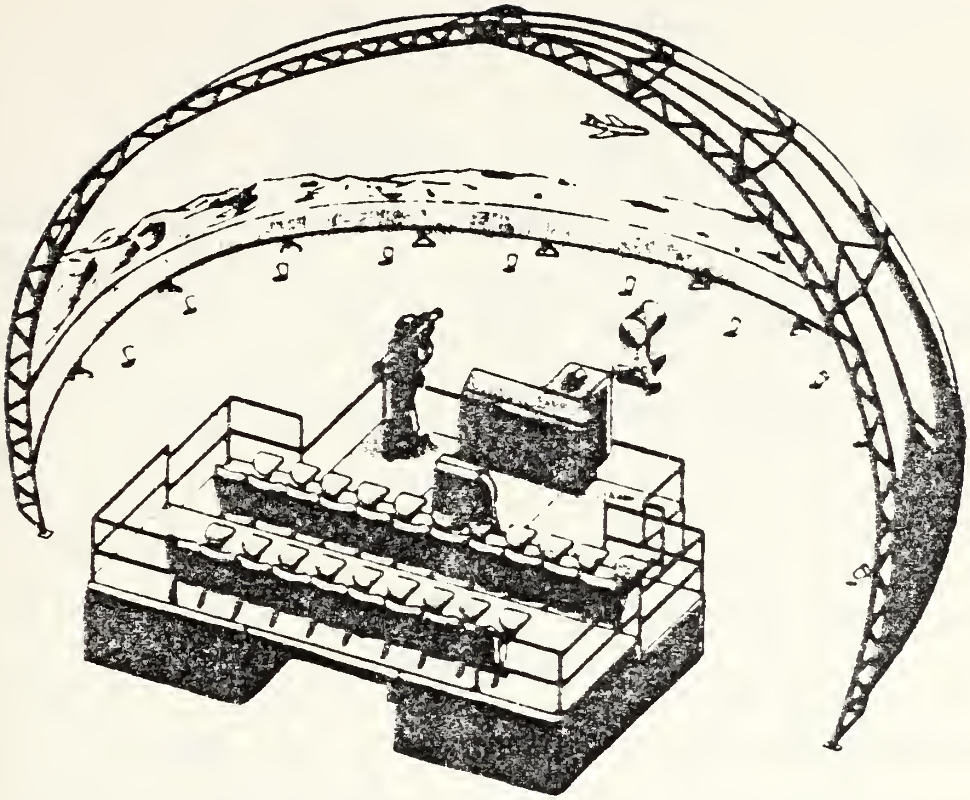


Figure 14. MTS Simulator Room

personnel tested closely approximates the structure, by grade, normally found in VULCAN and CHAPARRAL squads and REDEYE teams. Hence, the test sample accurately reflects the larger squad/team population throughout SHORAD units in the Army. Personnel tested thus appear to be representative of the general SHORAD population at large who will be performing such tasks under actual combat conditions.

D. TEST DESIGN AND DATA COLLECTION

The MTS experiment was designed to test the hypothesis generated in paragraph A above using the two measures of

TABLE IV

Test Units and Test Dates

Duty	MOS	Quantity Tested	Unit	Test Date
CHAPARRAL Crewman	16P	28	BTRY D, 1/51 ADA	4 MAR 83
VULCAN Crewman	16R	28	BTRY A, 1/51 ADA	28 FEB 83
REDEYE Crewman	16S	28	BTRY A, 1/51 ADA	14 APR 83

TABLE V

Personnel Data

	RANK						AGE (YRS)			MOS EXPERIENCE (YRS)		
MOS	E1	E2	E3	E4	E5	E6	Min	Max	Avg	Min	Max	Avg
16P	8	4	2	8	3	3	17	37	23.9	.38	8	2.76
16R	1	8	6	6	3	4	18	37	23.0	.33	10	2.77
16S	0	12	9	7	0	0	18	30	19.9	.33	4.33	1.38
TOTAL	9	24	17	21	6	7						

effectiveness designated in paragraph B. Test personnel were individually evaluated on the time required to locate a stationary target at various locations on the simulator screen using the three alternative search patterns. Each individual was tested once on each of the three search patterns. Target size and luminosity were adjusted to simulate an aircraft at maximum detection range. Consequently,

the target was clearly visible with direct foveal vision but rapidly became indistinguishable as line-of-sight was directed away from the target. The target was placed randomly at one of four elevation angles above the horizon for each trial. Target elevation was selected from one of the following angles: less than 1 degree (just above the horizon line), 5 degrees, 15 degrees, or 25 degrees. Target azimuth was also randomly adjusted within the search sector for each trial. Additionally, since each individual was tested successively three times, once for each search pattern, the order of the search pattern was rotated to preclude any confounding of learning effects with search pattern type. To summarize, each test subject was timed to determine how long he took to detect a target placed randomly in azimuth and randomly at one of four elevation angles. For each test subject this process was repeated three times, once for each search pattern.

The test design was therefore structured as a two-way layout with seven observations per cell. The three competing search patterns were selected as the row factor and the four target elevation angles as the column factor. Three test design matrices were developed, one for each SHORAD MOS. Selection of this particular test design enables distributions of target detection times to be obtained for a given search pattern at each target elevation angle. Thus, each cell, which specifies a particular search pattern and target elevation angle, contains seven data points. Since each MOS

consists of similarly structured test design matrices, examination of any particular cell provides a distribution of 21 data points. The design therefore provides relative indications of effectiveness, as measured by target detection times, for each of the three search patterns. The design also enables comparisons of search pattern effectiveness at different target elevation angles which correspond to the search region derived from an analysis of the threat (refer to Chapter III, paragraph B). Hence it is anticipated that this design will indicate which search patterns are most effective at particular target elevation angles. The design also provides significant flexibility when performing statistical data analysis:

1. Test results can be analyzed using parametric tests such as two-way analysis of variance (ANOVA) and one-way ANOVA (multiple replications per cell) procedures, if essential assumptions are met, or

2. Various applicable non-parametric procedures can be used if assumptions for ANOVA use cannot be met.

Maintaining separate data sets for each MOS also enables subsequent comparisons between them to be made.

Data collection was accomplished using individual data collection forms. These individual data sheets accomplished several purposes:

- Personal data, such as age and experience, was elicited from the test subject and entered on the form (this data was summarized and has been presented in Table V).

- Coded target location information for each of the three trials was listed on the form to assist the test controller during the actual conduct of the test. Target location information (i.e., azimuth and elevation angle) was extracted from the test design matrix.
- Test results from each trial were recorded on the form for subsequent statistical analysis, and
- The test subject was afforded the opportunity to indicate on the form his own personal preference and opinion on the alternative search patterns.

Consolidation of test results was accomplished for each MOS using an MOS consolidated collection sheet. Provisions were also made to record any false-detect or no-detect results. An example of an Individual Data Sheet is provided at Figure 15.

E. TEST PROCEDURES

Since no provision exists to stop the aircraft film projector without destroying a frame, the unfiltered IR dot was used as the target. This was accomplished by disengaging the IR generator from the aircraft film projector and then removing the IR filter source. The dot's intensity and location on the screen could be controlled. Intensity and size were initially adjusted to simulate an aircraft at maximum detection range. Once these initial adjustments were made, target intensity and size remained fixed throughout the experiment. Although the simulator cannot simulate

REDEYE (16S) INDIVIDUAL DATA SHEET TROOP # ___________

RANK ____________

AGE (IN YEARS) ____________

TIME SPENT IN 16 SERIES MOS (IN YEARS AND MONTHS) ________

TEST DATA:

RUN #	1	2	3
SCAN TYPE	____	____	____
EL BAND	____	____	____
AZ BAND	____	____	____
TIME	____	____	____
FALSE DETECT			
AZ BAND	____	____	____
EL BAND	____	____	____
TIME	____	____	____
NO DETECT	____	____	____

WHICH SEARCH AND SCAN TECHNIQUE IS MOST NATURAL FOR YOU TO USE? (CHECK ONE)

VERTICAL ______

LATERAL ______

HORIZON ______

WHICH TECHNIQUE DO YOU BELIEVE WILL BE THE MOST EFFECTIVE IN DETECTING THREAT AIRCRAFT IN A COMBAT SITUATION? (CHECK ONE)

VERTICAL ______

LATERAL ______

HORIZON ______

ANY COMMENTS YOU MAY HAVE:

Figure 15. Individual Data Sheet

the sun or sun glare, the quadrasphere does reasonably simulate the sky with darkest background luminosity at zenith and lightest near the horizon. Controls are available for adjusting both sky background luminosity and horizon luminosity. These luminosities were adjusted to simulate viewing conditions on a clear day and then remained fixed throughout the experiment. Specific control settings for target, sky, and horizon luminosities are provided at Appendix D.

On the test date participating subjects were thoroughly briefed in the simulator on the search technique to be used and informed that the entire simulator screen would serve as the sector of search (180 degree search sector). In most cases subjects were completely familiar with the two search and scan patterns currently used (i.e., lateral and vertical). All subjects were also directed to focus their gaze on the general area of the screen where the target, simulated by the unfiltered IR dot, was temporarily located. Test subjects who could not clearly see the target on the screen, due to myopia (nearsightedness) or poor minimum perceptible acuity, were not subsequently tested. Once the briefing was completed all personnel departed the simulator and remained in the MTS classroom until individually tested. During this waiting period test personnel completed the personal data portion of the individual data sheets. The actual experiment was then conducted as follows:

1. A test subject was brought into the simulator room. He was directed to the center of the training platform, which is located equidistant (20 feet) from all points on the quadrasphere screen surface. The subject was not allowed to face the simulator screen until directed to do so.

2. The target was directed to a specific location on the simulator screen in accordance with the target location information on the individual data sheet.

3. The subject was directed to use one of the three search patterns.

4. From his position on the training platform, the subject was directed to face the screen and commence searching. The subject was timed from search initiation until target detection. The controller measured time to detection to the nearest tenth of a second using a stopwatch. The test subject was given a maximum of two minutes (120 seconds) to detect the target. Failure to detect the target within this interval was designated as a "no detect". After either target detection occurred or the 120 second time limit elapsed, the subject was again directed to face away from the screen. The controller recorded either the detection time or "no detect", as appropriate, on the Individual Data Sheet in the applicable "run #" column (either trial number 1, 2 or 3; refer to Figure 15).

5. The target was then relocated on the screen for the next trial in accordance with the location information on

the individual data sheet and the above procedures were repeated using a different search technique.

6. The entire process was repeated three times for each test subject until all personnel were tested.

Upon completion of the test, personnel were afforded the opportunity to indicate their preference and opinion regarding the effectiveness of the three alternative patterns. This information was recorded on their respective individual data sheets for subsequent evaluation.

Due to different training schedule commitments and field exercises among the participating air defense units and also to routinely scheduled MTS training, all personnel were not tested on the same day, week, or even month. However, as indicated in Table IV, all personnel of a particular MOS were tested on the same day.

F. TEST RESULTS

1. Data Analysis Logic

As previously mentioned, the test design provides for significant flexibility once data collection and reduction have been accomplished. The test was designed to facilitate statistical hypotheses testing using a standard two-way analysis of variance (ANOVA) with multiple replications per cell. Although ANOVA techniques are relatively robust parametric tests they do require several assumptions. When such assumptions are not sufficiently met ANOVA tests may provide biased, or even erroneous, results. In contrast,

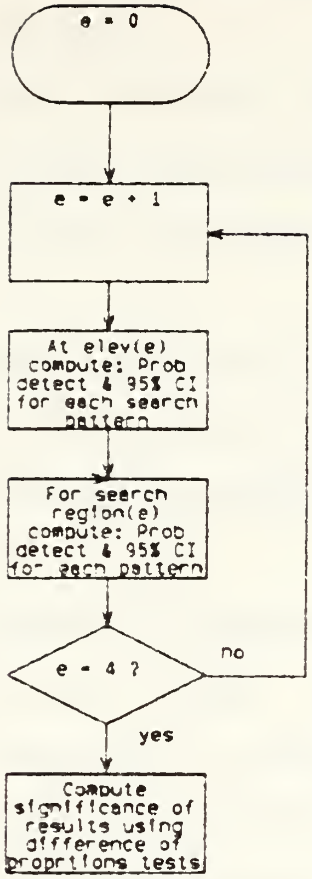
nonparametric techniques require fewer assumptions and, in cases where assumptions essential for ANOVA tests are not sufficiently met, provide unbiased and more powerful test results than their parametric ANOVA equivalent. Thus, the test design allows the decision to use either parametric or nonparametric procedures to be suggested by the data. Regardless of which of the two statistical approaches is ultimately used, both approaches contain specific tests which answer essentially equivalent hypotheses.

The test design enabled the statistical analysis logic, generalized in Figure 16, to be developed. Detailed logic flow charts, which describe the actual hypotheses generated and applicable statistical tests used to test those hypotheses, are provided in Appendix D. Note that for the second MOE, each successive objective can be achieved using either parametric or nonparametric statistical tests. In all cases, statistical tests have been selected which relate directly to the MOEs previously established to answer the general hypothesis that the horizon search pattern is more effective than the two currently used patterns. The impact of secondary factors of interest, such as possible search effectiveness differences as a consequence of MOS, age, and experience, are also examined.

2. Data Analysis

Test data was extracted from the individual data sheets and consolidated into MOS Master Data Collection

MOE #1:



MOE #2:

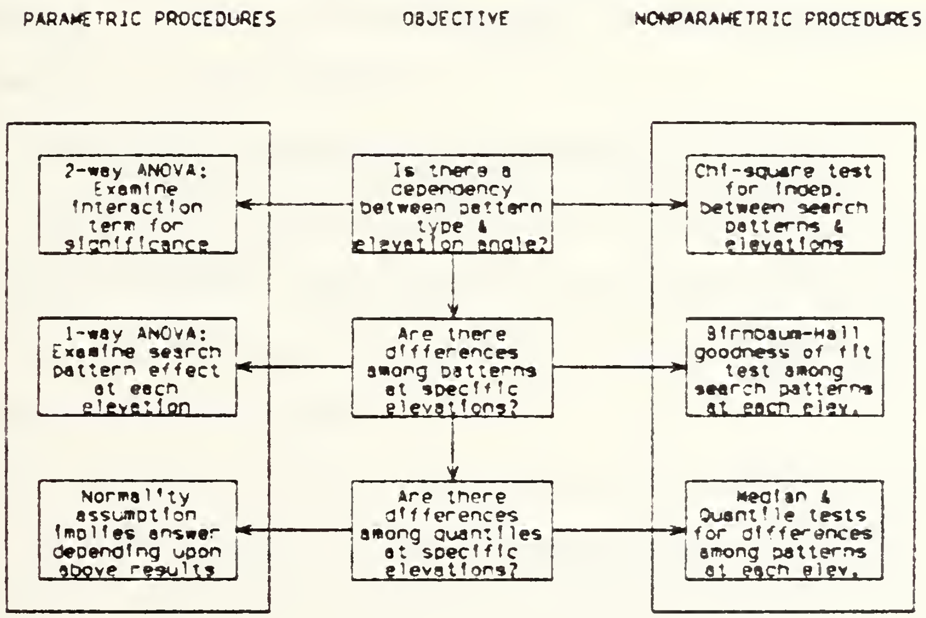


Figure 16. Statistical Analysis Logic

Sheets. Pertinent results are summarized and tabulated here for each of the two MOEs:

- Probability of target detection (MOE #1): See Table VI for "no detect" locations and columns 1 through 3 of Tables VII and VIII for point estimates of detection probabilities.

- Time to target detection given that detection occurs (MOE #2): See Tables IX through XVII for detection time empirical probability density functions and quantile bar graphs.

Data is presented for specific target elevation "bands" as well as for target elevation angles. Appendix D also contains detection time histograms. Analysis of the data reveals that essential assumptions required for the parametric ANOVA procedures are not adequately met. Consequently, nonparametric procedures were subsequently used for hypotheses testing. A detailed explanation of ANOVA model inadequacy is presented in Appendix D.

3. Statistical Results of Hypothesis Testing

Results of hypothesis tests performed in accordance with the appropriate nonparametric techniques specified in the statistical analysis logic flow chart (refer to Figure 16) are summarized as follows:

- MOE #1: See columns 4 of Tables VII and VIII for significance between search pattern detection probabilities.

- MOE #2: See Tables XVIII and XIX for significance between detection time empirical distribution functions and also significance between quantiles.

TABLE VI

No Detect Location Chart
(The Chart Represents The Search Area on the MTS Screen and Shows No Detect Locations by MOS and Search Pattern)

LEGEND:

1st Letter (MOS)	2nd Letter (Search Pattern)
C - CHAPARRAL	H - HORIZON
R - REDEYE	L - LATERAL
V - VULCAN	V - VERTICAL

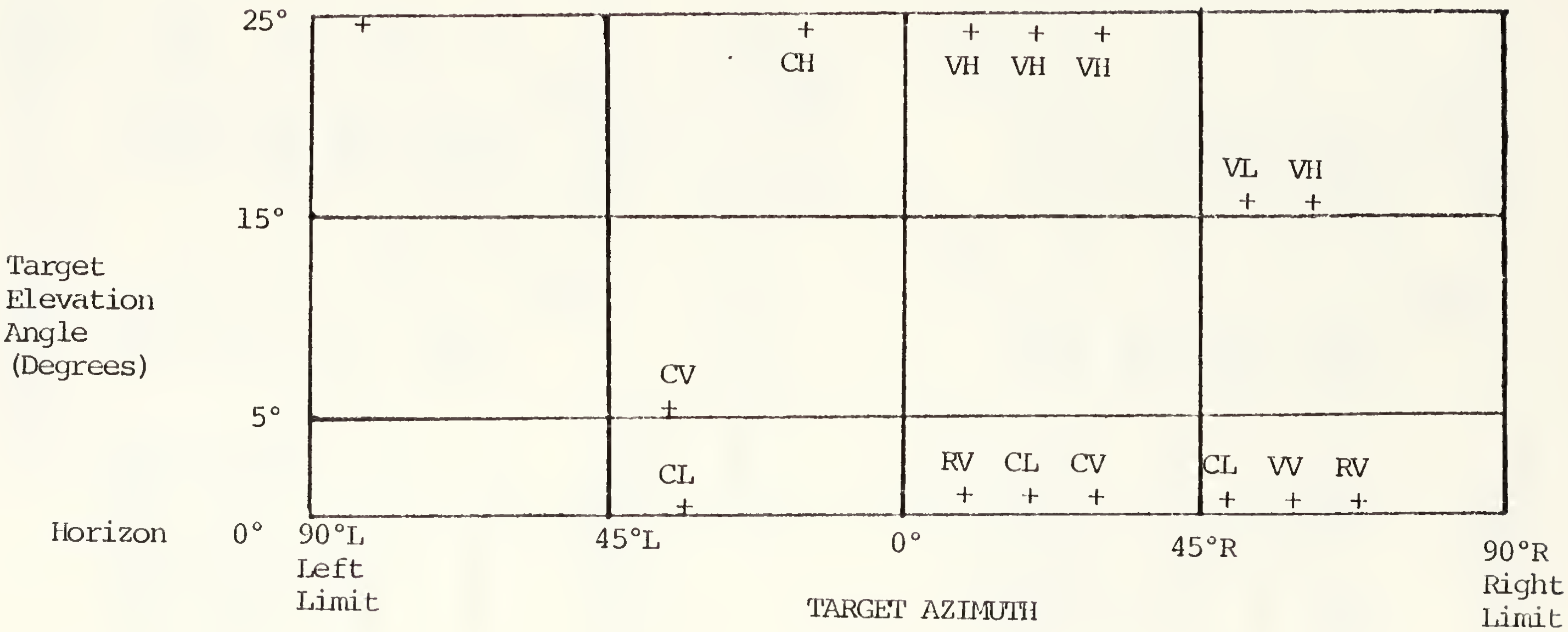


TABLE VII

PROBABILITY OF TARGET DETECTION (ELEVATION ANGLES)*

		Search Pattern (1) Lat		(2) Vert		(3) Hor		Significant Differences Among Patterns? (4)
Target Elevation Angles (Degrees)	25	1.0	[1.0 .83]	1.0	[1.0 .83]	.76	[.92 .52]	$P_{lat} > P_{hor}$ $(P<.05)$ $P_{vert} > P_{hor}$ $(P<.05)$
	15	.95	[.99 .76]	1.0	[1.0 .83]	.95	[.99 .76]	No Difference
	5	1.0	[1.0 .83]	.95	[.99 .76]	1.0	[1.0 .83]	No Difference
	<1	.96	[.97 .64]	.81	[.95 .58]	1.0	[1.0 .83]	$P_{hor} > P_{vert}$ $(P<.05)$ $P_{hor} > P_{lat}$ $(P<.1)$
	TOTAL	.95		.94		.93		

TABLE VIII

PROBABILITY OF TARGET DETECTION (SEARCH REGION)*

		Search Pattern (1) Lat		(2) Vert		(3) Hor		Significant Differences Among Patterns? (4)
Target Elevation Band (Degrees)	≤25	.95	[.98 .88]	.94	[.98 .87]	.93	[.97 .85]	No Difference
	≤15	.94	[.98 .84]	.92	[.97 .82]	.98	[1.0 .91]	No Difference
	≤ 5	.93	[.98 .81]	.88	[.96 .73]	1.0	[1.0 .91]	$P_{hor} > P_{vert}$ $(P<.05)$ $P_{hor} > P_{lat}$ $(P<.1)$
	< 1	.86	[.97 .64]	.81	[.95 .58]	1.0	[1.0 .83]	$P_{hor} > P_{vert}$ $(P<.05)$ $P_{hor} > P_{lat}$ $(P<.1)$

*NOTE: Cell numbers in [ ] indicate 95% confidence interval on cell probability.

TABLE IX: EMPIRICAL DETECTION TIME DENSITIES: <1 DEGREE

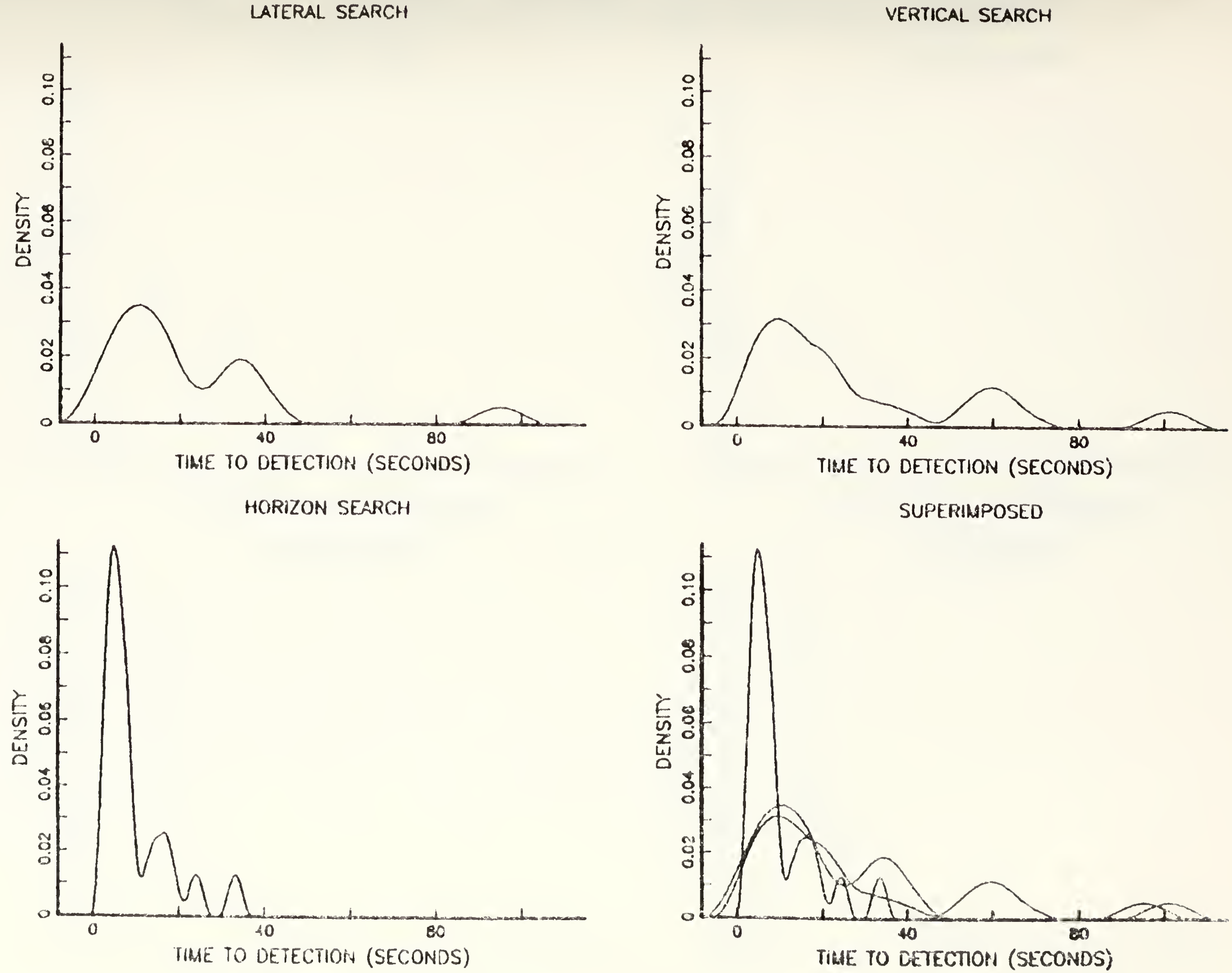


TABLE X: EMPIRICAL DETECTION TIME DENSITIES: 5 DEGREES

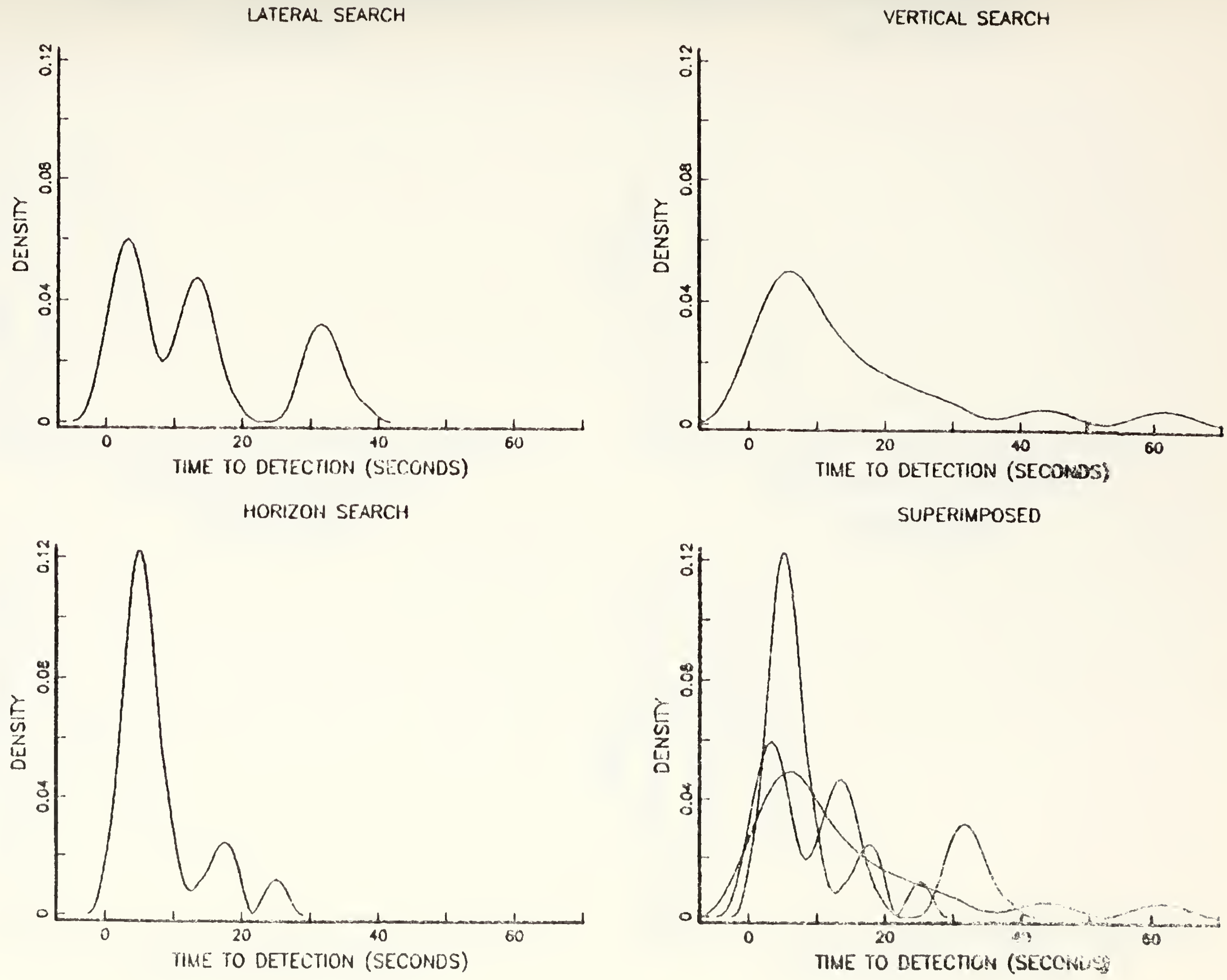


TABLE XI: EMPIRICAL DETECTION TIME DENSITIES: 15 DEGREES

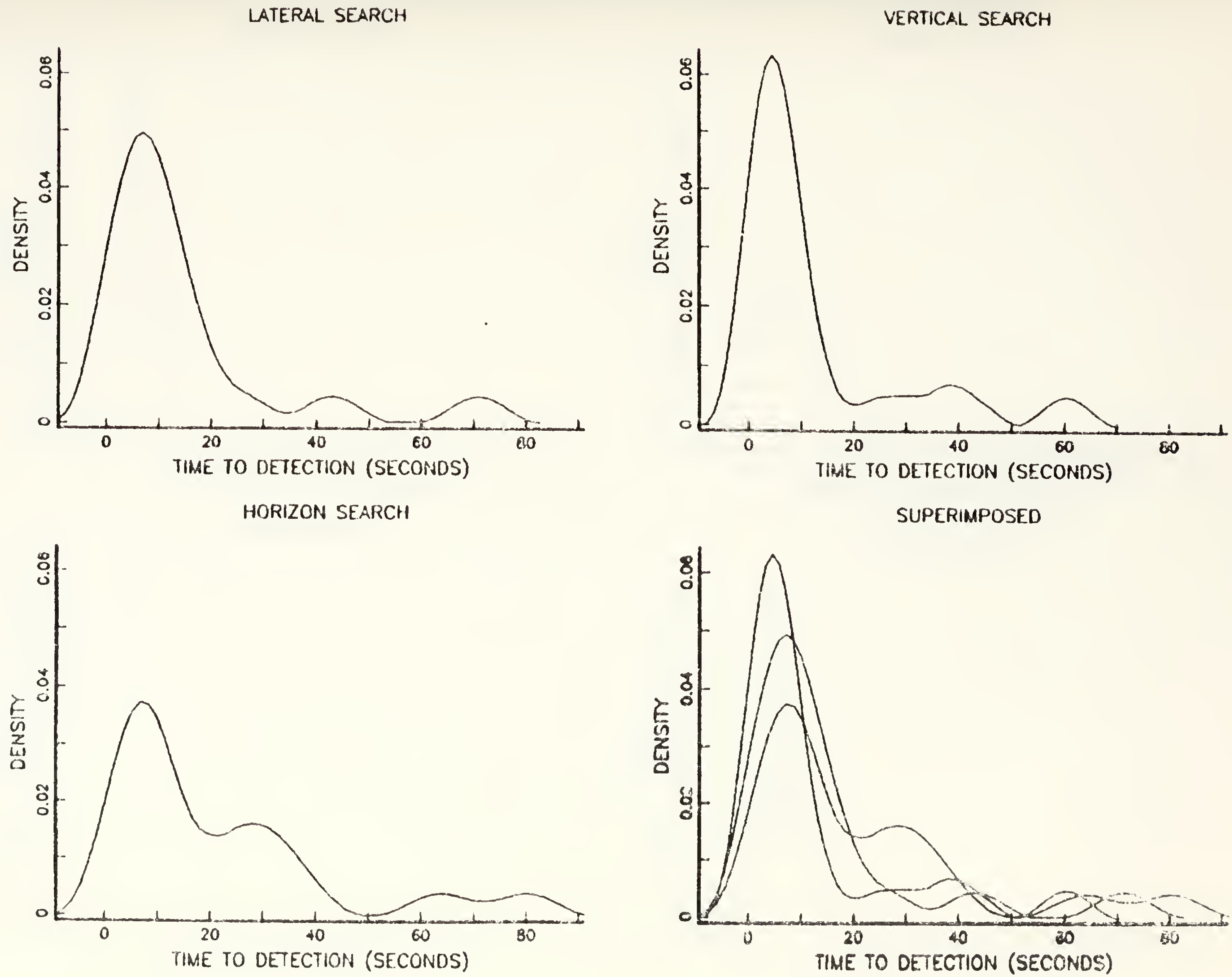


TABLE XII: EMPIRICAL DETECTION TIME DENSITIES: 25 DEGREES

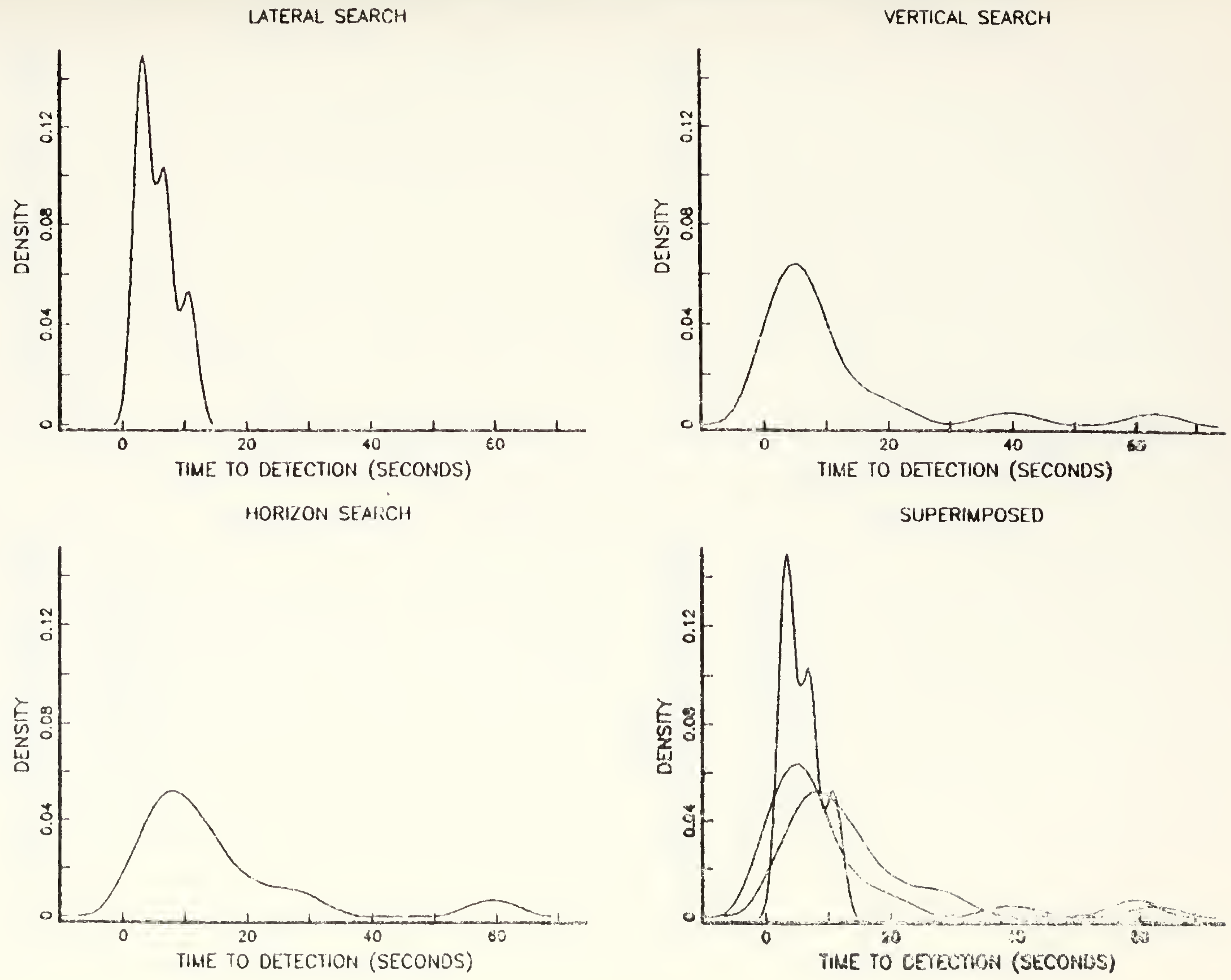


TABLE XIII: EMPIRICAL DETECTION TIME DENSITIES: ≤5 DEGREES

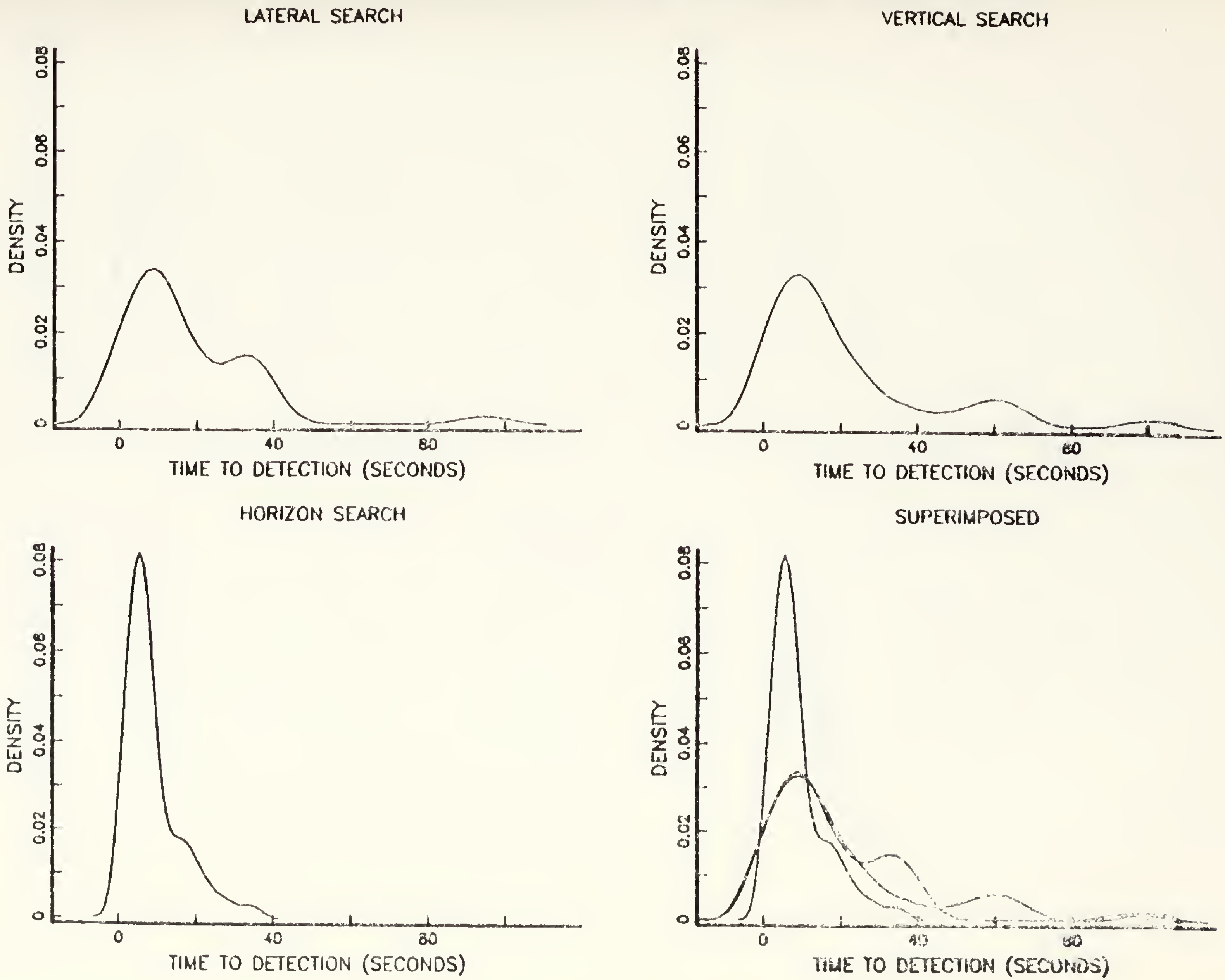


TABLE XIV: EMPIRICAL DETECTION TIME DENSITIES: ≤15 DEGREES

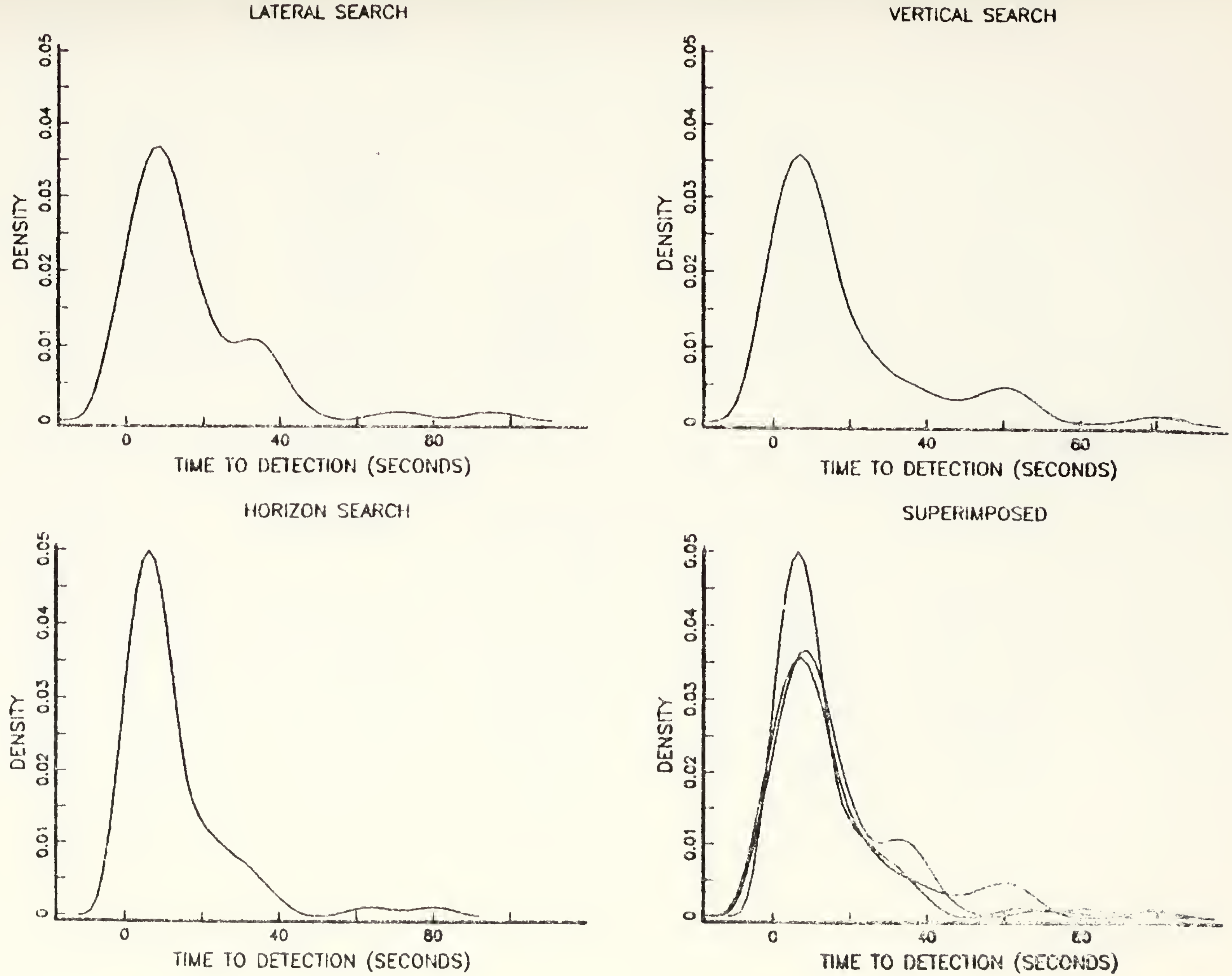


TABLE XV: EMPIRICAL DETECTION TIME DENSITIES: ≤25 DEGREES

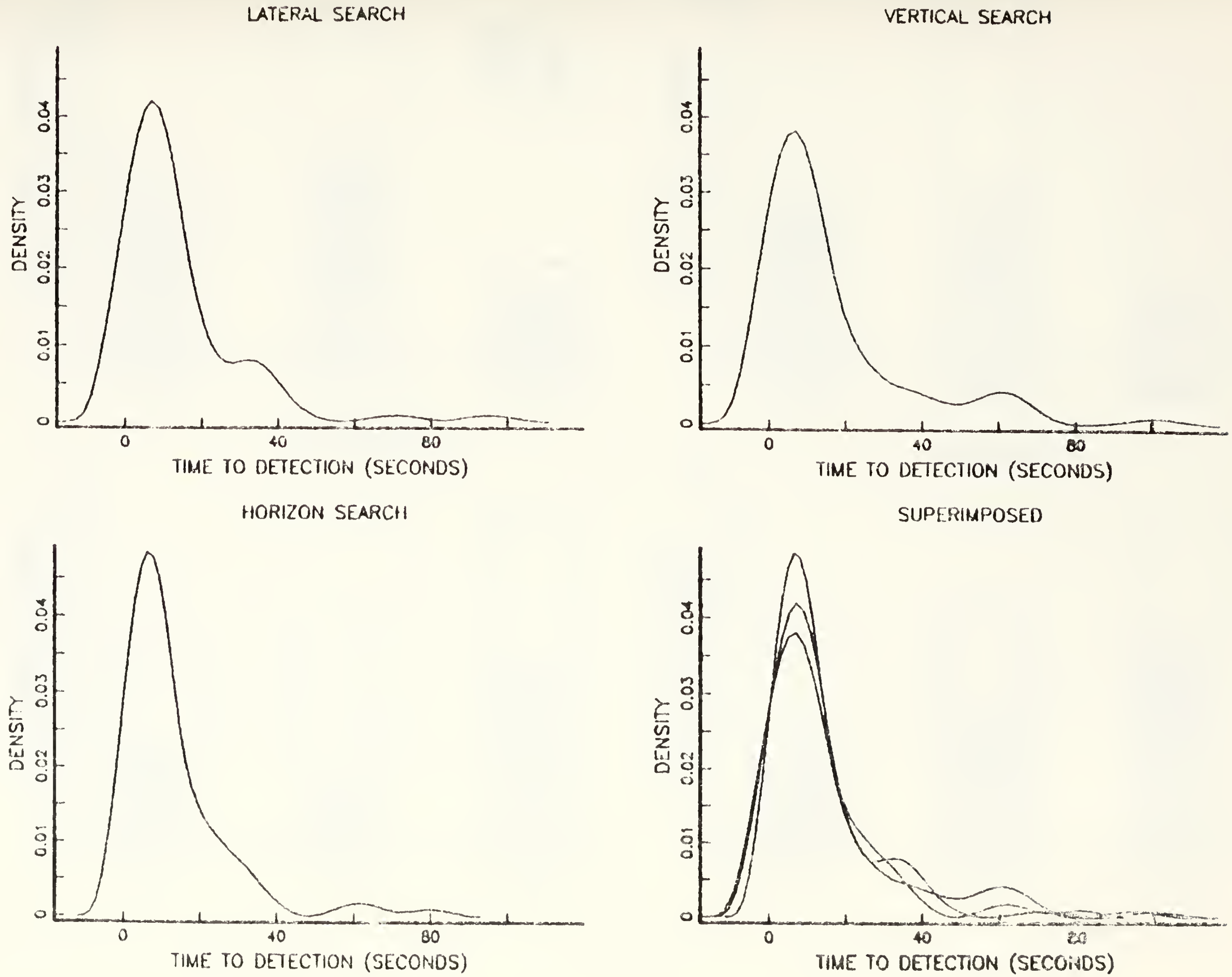


TABLE XVI SEARCH PATTERN QUANTILES: ALL ELEVATIONS

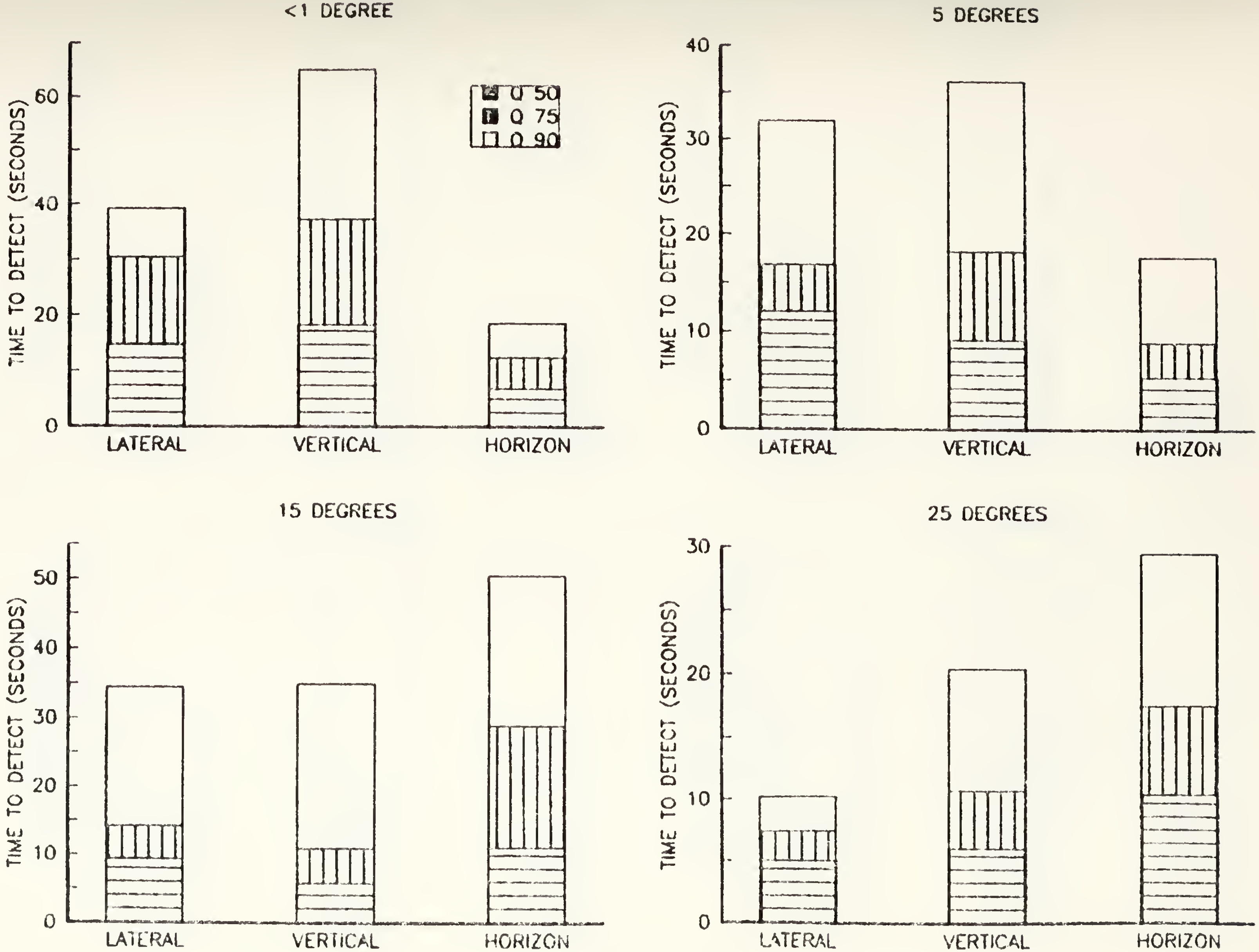


TABLE XVII: SEARCH PATTERN QUANTILES: ELEVATION BANDS

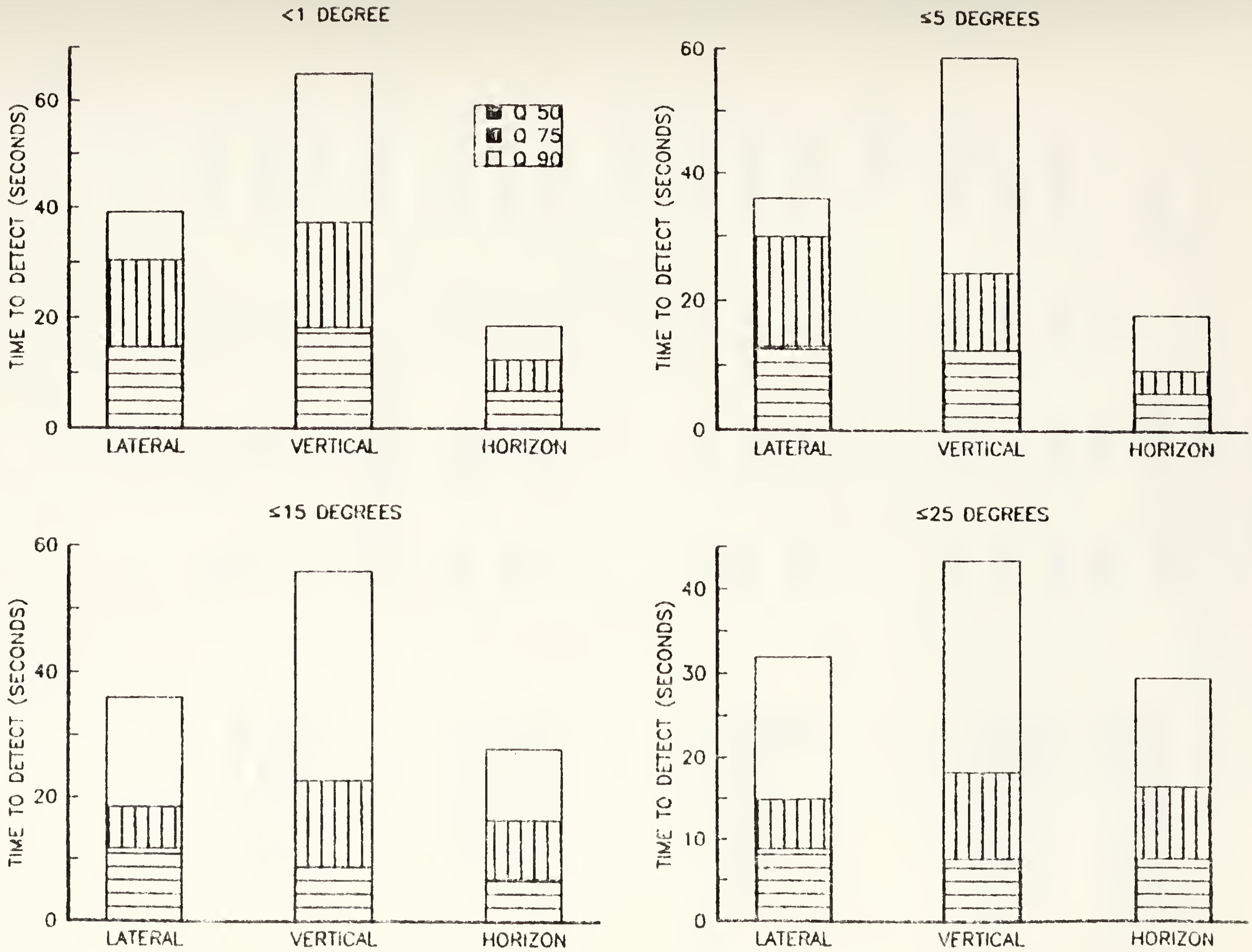


TABLE XVIII

Tabulated Quantile Data for Elevation Angles

	Q_{50}	Q_{75}	Q_{90}	Significance Level of Differences in Distns or Quantiles
- ≤ 1 DEGREE (Significant Dist^n)				
LATERAL	14.8	30.4	39.2	Distns: Horizon Results In Less Time to Detection ($p < .05$)
VERTICAL	18.2	37.2	65.0	
HORIZON	6.8	12.4	18.5	
- 5 DEGREES				
LATERAL	12.1	16.9	32.0	Q_{90}: Horizon Results In Less Time to Detection ($p < .05$)
VERTICAL	9.15	18.3	36.3	
HORIZON	5.4	9.0	17.8	
- 15 DEGREES				
LATERAL	9.4	14.15	34.5	No Significant Differences Between Distn's or Quantiles for Each Elevation
VERTICAL	5.8	10.9	35.0	
HORIZON	11.1	28.95	50.6	
- 25 DEGREES (Significant Dist^n)				
LATERAL	5.0	7.4	10.2	Distns: Lateral Results In Less Time to Detection
VERTICAL	6.0	10.7	20.4	
HORIZON	10.35	17.45	29.5	

TABLE XVIX

Tabulated Quantile Data for Search Regions

	Q_{50}	Q_{75}	Q_{90}	Significance Level of Differences in Distn's or Quantiles
- $\leq$ 1 DEGREE				
LATERAL	14.8	30.4	39.2	Distns: Horizon Results In Less Time to Detect ($p < .05$)
VERTICAL	18.2	37.2	65.0	
HORIZON	6.8	12.4	18.5	
- $\leq$ 5 DEGREES				
LATERAL	13.0	30.0	36.0	Distns: Horizon Results In Less Time to Detect ($p < .01$)
VERTICAL	12.5	24.5	59.0	
HORIZON	5.9	9.4	18.0	
- $\leq$ 15 DEGREES				
LATERAL	11.8	18.5	36.0	Q_{50}: Horizon Results In Less Time to Detect ($p < .01$)
VERTICAL	8.75	22.8	56.0	
HORIZON	6.9	16.4	28.0	
- $\leq$ 25 DEGREES				
LATERAL	8.8	14.9	32.0	No Significant Differences Between Distns or Quantiles for Each Elevation
VERTICAL	7.6	18.2	43.4	
HORIZON	7.6	16.4	29.5	

Specific null and alternative hypotheses, nonparametric tests, critical levels, and test statistics used to answer each objective listed in Figure 16 are further discussed in Appendix D.

4. Secondary Experimental Results

Since identical replicated two-way layouts were repeated three times for the test, once for each MOS, the design enabled differences in detection probabilities and times between MOSes to be examined also. Summarized results for detection probabilities and both median and upper quantiles for each MOS are provided at Table XX. MOS empirical detection time densities are presented in Table XXI. Multiple paired comparisons between probabilities of detection reveal that REDEYE personnel (16S) have a significantly higher detection probability than either CHAPARRAL (16P) or VULCAN (16R). This result was not surprising since REDEYE personnel routinely conduct training in the MTS whereas VULCAN and CHAPARRAL do not. Also, statistical tests reveal that REDEYE has significantly shorter detection times than CHAPARRAL and, although not anticipated, that VULCAN has significantly shorter detection times than CHAPARRAL.

Individual data sheets also provide personal age and experience data on each of the test subjects. Detection probabilities are provided at Table XXII for these two factors. Subsequent statistical testing revealed that neither detection probabilities nor detection times significantly differed as a result of age or experience. Specific

tests used which provided these conclusions are provided in Appendix D.

5. Questionnaire Opinion Results

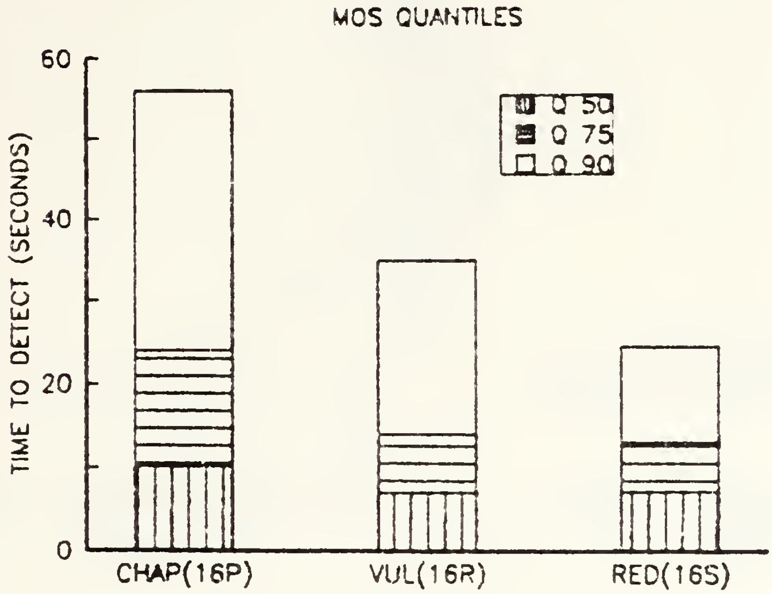
Personnel were asked to respond to two specific questions upon completion of the test (refer to Fig. 15):

- "Which of the three search patterns do you feel is the most natural for you to use?"
- "Which of the three search patterns do you feel will be the most effective in a combat situation?"

The questionnaire results are provided at Table XXIII. It is noteworthy that test subjects perceived the horizon search to be the most natural pattern to use and also the most effective relative to the two currently recommended patterns.

TABLE XX

MOS Detection Probabilities and Detection Time Quantiles



CHAP (16P)	VULCAN (16R)	REDEYE (16S)	TOTAL
.93	.92	.98	.94

SIGNIFICANCE:

- REDEYE is significantly better than CHAPPARAL ($p < .1$)

- REDEYE is significantly better than VULCAN ($p < .05$)

TABLE XXI: DETECTION TIMES BY MOS

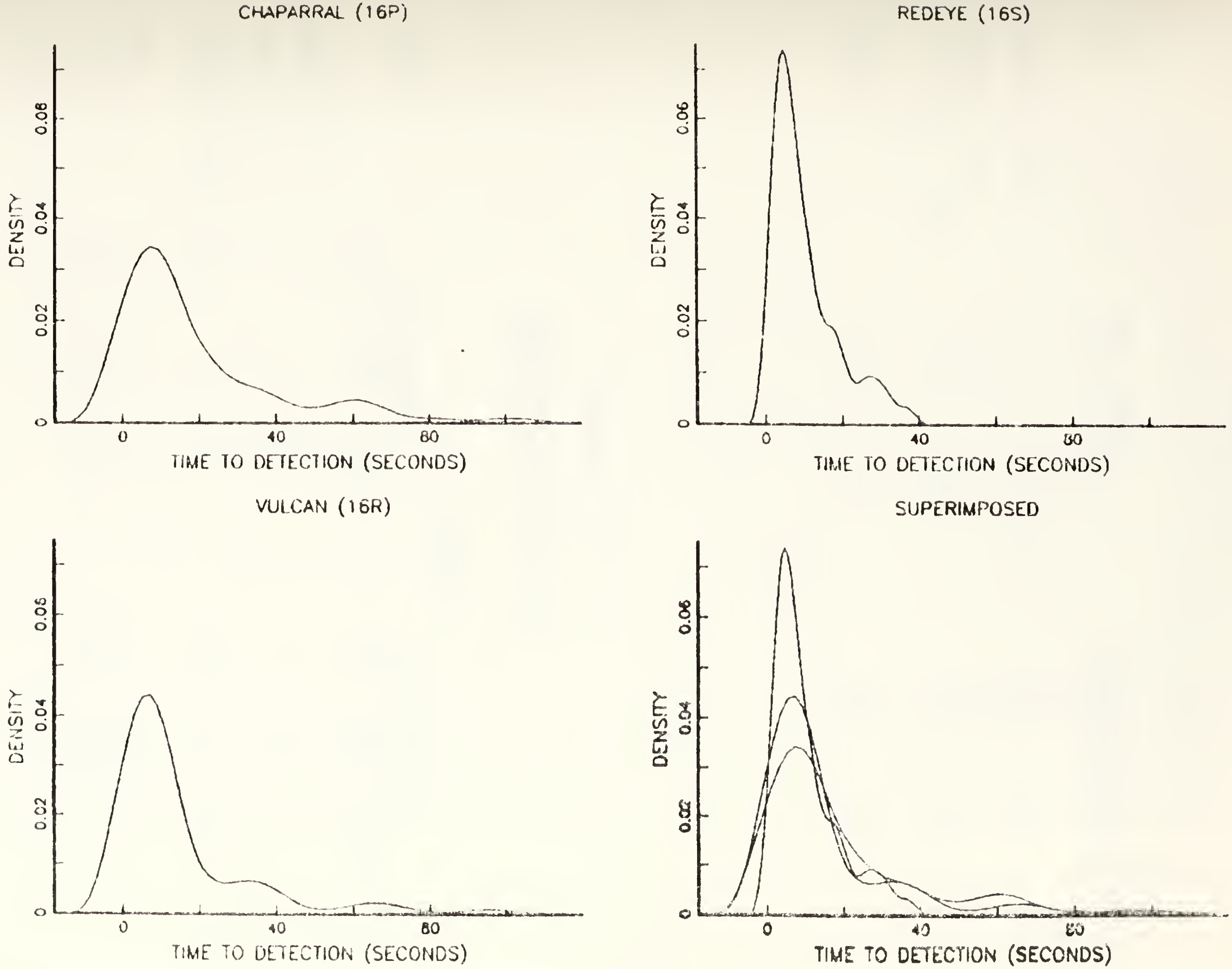


TABLE XXII

Detection Probabilities by Age and Experience

MOS	AGE (YEARS)		EXPERIENCE (YEARS)	
	≤ 20	> 20	≤ 2	> 2
REDEYE (16S)	.98	.97	.97	1.0
VULCAN (16R)	.91	.91	.90	.93
CHAPARRAL (16P)	.97	.88	.97	.88
TOTAL	.96	.92	.95	.93

TABLE XXIII

Questionnaire Results
(Refers to Figure 15)

MOS	QUESTION #1 (NATURAL)			QUESTION #2 (EFFECTIVE)		
	LAT	VERT	HOR	LAT	VERT	HOR
REDEYE (16S)	9	5	14	4	6	18
VULCAN (16R)	7	9	12	9	8	11
CHAPARRAL (16P)	12	4	12	15	1	12
TOTAL	28	18	38	28	15	41
%	33.3	21.4	45.2	33.3	17.9	48.8

V. COMPARATIVE ANALYSIS

A. TECHNIQUES USED TO COMPARE EFFECTIVENESS OF ALTERNATIVE SEARCH PATTERNS

Two categories of techniques will be used to evaluate and compare the relative effectiveness of each of the three alternative search patterns:

- Quantitative evaluations based upon statistical analysis of experimental test results, and
- Judgemental evaluations, which are founded upon results derived from previous research, comparing the theoretical effectiveness of the three search patterns.

The desired goal, upon completion of the two evaluation techniques specified above, is to ascertain how well the experimental test results conform to expectations suggested by known theoretical results.

Secondary objectives, such as possible differences in effectiveness between MOSes, experience levels, and age groups will be addressed. Additionally, the collective opinion of the test subjects, a crucial consideration often overlooked, will be investigated to determine whether or not the personnel who will ultimately be responsible for visual aircraft detection in combat perceive any differences in effectiveness and which technique, given a choice, they would prefer to use.

Consideration of these methods for evaluating and comparing search pattern effectiveness will provide answers to the following critical questions:

- "Which pattern is most effective according to experimental test results?"

- "Which pattern(s) appear to possess those attributes deemed essential by search and detection theory as well as other relevant theoretical results?"

- "Which pattern(s) is(are) preferred and considered most effective by those who are responsible for using them?"

B. COMPARISON USING EXPERIMENTAL TEST RESULTS

Statistical analysis of the experimental test data previously summarized in Tables VI through XIX reveal the results listed herein.

1. Primary Objectives (Search Pattern Effectiveness)

a. MOE #1: Probability of Detection (refer to TABLES VII and VIII)

- Probability of target detection varies significantly depending upon which pattern is used in which region or specific target elevation angle.

- In the low to medium search regions (i.e., target elevation bands: $<$ 1 degree, $\leq$ 5 degrees, $\leq$ 15 degrees), the horizon search consistently results in higher detection probabilities. In the two lower search regions the horizon search results in significantly higher (in a statistical sense) detection probabilities.

- The horizon search results in significantly higher detection probabilities at the lowest target elevation angle, is comparable at 5 and 15 degrees, and significantly deteriorates at 25 degrees. In comparison, the lateral and vertical searches provide significantly lower detection probabilities for low elevation (< 1 degree) targets, but significantly higher detection probabilities for the highest (25 degrees) targets.

b. MOE #2: Time to Target Detection, Given Detection Occurs (refer to Tables XVI Through XIX)

- Within the two lower search regions (< 1 degree and ≤ 5 degrees), the horizon search results in significantly less time to detect a target. The combination of a relatively low mean and small variance for the horizon search within these elevation bands results in detection times which vary from one-half (for median detection times) to less than one-quarter (for 90th quantile times) of those for the other search patterns.

- Within the medium search region (≤ 15 degrees), the horizon search results in lower detection times. For median values this lower time is statistically significant. Throughout the entire search region (≤ 25 degrees) horizon search detection times are still the lowest although differences are not statistically significant among the patterns.

- For specific elevation angles, as previously noted, the horizon search provides significantly lower detection

times for targets near the horizon (< 1 degree). At 5 degrees the horizon search continues to exhibit lower detection times, although only the 90th quantile results are statistically significant.

- At 15 degrees no statistical difference exists among the search patterns although it is apparent that the horizon search is beginning to lose its effectiveness. At 25 degrees horizon search effectiveness has significantly deteriorated. At this elevation angle the lateral search provides significantly lower detection times than either the horizon or vertical search patterns.

c. Summary of Experimental Results

Analysis of experimental test data conclusively reveals that the horizon search produces significantly more effective results at lower target elevation angles. Use of the horizon search yields not only a significantly higher probability of detecting the target but also significantly reduces the amount of search time necessary for detection to occur. The superior effectiveness of the horizon search in detecting targets at specific elevation angles is retained up through at least 5 degrees but is substantially reduced by 25 degrees. However, an evaluation of the cumulative effectiveness of search patterns within successively larger search regions (i.e., target elevation bands) clearly reveals that the horizon search provides greater detection probabilities and reduced time for target detection. This overall

effectiveness of the horizon search pattern is far superior at low elevation regions, remains significantly greater up through 15 degrees, and, even at 25 degrees, has not been surpassed by either of the two currently suggested patterns. Conversely, both the lateral and vertical search patterns provide very poor results at low, near-horizon target elevation bands. However, if consideration is limited strictly to these two currently used patterns and the horizon search is excluded from consideration, then the lateral search appears to be more effective than the vertical.

Results of this statistical analysis are also summarized in Table XXIV to provide a quick reference for comparative analysis among the alternative search patterns.

2. Secondary Objectives

a. Differences in Age, MOS, and Experience (refer to Tables XX through XXII)

Analysis of possible differences among the three MOSes reveal that REDEYE (16S) personnel were more likely to detect the target and they also tended to require less time to do so.

Neither age nor experience proved to be a significant factor in target detection. Although personnel 20 years of age or younger had a slightly higher detection probability than those over 20 years of age, this difference is not statistically significant. Two of the three MOSes (REDEYE and VULCAN) showed slightly greater detection probabilities as a result of job experience (greater than two

TABLE XXIV

Statistical Analysis Summary

PROBABILITY OF TARGET DETECTION:

		SEARCH PATTERN TYPE		
		LATERAL	VERTICAL	HORIZON
SEARCH REGION	< 25	ADEQUATE	ADEQUATE	ADEQUATE
	< 15	ADEQUATE	ADEQAUTE	EXCELLENT
	< 5	ADEQUATE	POOR	EXCELLENT
	< 1	POOR	POOR	EXCELLENT

QUALITATIVE INDICATOR DEFINITIONS:

EXCELLENT - DETECTION PROBABILITY > .95

ADEQUATE - .90 < DETECTION PROBABILITY < .95

POOR - DETECTION PROBABILITY < .90

TIME TO TARGET DETECTION:

SEARCH REGION	< 25	MIDDLE	WORST	BEST
	< 15	MIDDLE	WORST	BEST
	< 5	MIDDLE	WORST	BEST
	< 1	MIDDLE	WORST	BEST

QUALITATIVE INDICATOR DEFINITIONS:

BEST - COMPARATIVE ANALYSIS FOR BOTH POINT ESTIMATES FOR THE 50TH, 75TH, AND 90TH QUANTILES AND GRAPHICAL EVALUATION OF EMPIRICAL DENSITIES INDICATES THIS SEARCH PATTERN RESULTS IN LEAST TIME TO TARGET DETECTION.

MIDDLE - COMPARATIVE ANALYSIS REVEALS THIS SEARCH PATTERN TO REQUIRE LESS TIME TO DETECTION THAN "WORST" PATTERN BUT MORE TIME THAN "BEST" PATTERN.

WORST - COMPARATIVE ANALYSIS INDICATES THIS SEARCH PATTERN REQUIRES THE GREATEST TIME TO TARGET DETECTION.

years) but the overall difference among all tested personnel indicates that experience is not a significant factor. Differences in times to detection due to age and experience were found to be insignificant both within each MOS and also among all tested personnel.

b. Questionnaire Opinion Results (refer to Table XXIII)

Nearly 50 percent of tested personnel indicated on a post-test survey that they considered the horizon search to be the easiest to use and also the most effective in a combat situation. Survey results also reveal that the vertical pattern is considered least desirable because personnel regard it as both unnatural and ineffective.

C. COMPARISON OF THEORETICAL SEARCH PATTERN EFFECTIVENESS

Previously, in Chapter II.E, the discussion and evaluation of existing research literature regarding the visual ground-to-air search task enabled development of a list of attributes essential to an optimal search. This list, which was summarized in paragraph 5 of that section, allowed the horizon search to be derived as an alternative to the two existing search patterns. These essential attributes will now be used to evaluate the relative effectiveness of each of the search patterns in an effort to determine whether or not the horizon search appears to be an improvement from the perspective of "theoretical" considerations. Table XXV lists the various attributes of an effective search. Also

TABLE XXV

Theoretical Capabilities Summary

ATTRIBUTES OF AN EFFECTIVE SEARCH	SEARCH PATTERN EFFECTIVENESS		
	LATERAL	VERTICAL	HORIZON
1. GOOD COLLATERAL DUE DETECTION (GLINT, ROTOR FLICKER)	ADEQUATE	ADEQUATE	EXCELLENT
2. MINIMAL HEAD AND BODY MOVEMENT	POOR	POOR	EXCELLENT
3. USE OF FOVEAL VISION FOR STATIONARY TARGETS AND PERIPHERAL VISION FOR MOVING TARGETS	ADEQUATE	POOR	EXCELLENT
4. USE OF SMALL, QUICK SACCADIC MOVEMENTS TO MAXIMIZE FIXATION (VISUAL PROCESSING) TIME	POOR	POOR	EXCELLENT
5. MINIMAL TIME REQUIRED TO SEARCH A GIVEN AREA WITHOUT DEGRADING DETECTION PROBABILITY	POOR	POOR	EXCELLENT
6. COUNTERS EFFECTS OF EMPTY FIELD MYOPIA IN UNIFORM FIELD (CLOUD-LESS, CLEAR SKY) BY FORCING EYE TO MAINTAIN FOCUS AT OPTICAL INFINITY	POOR	ADEQUATE	EXCELLENT
7. SIMPLE AND NATURAL (EASY) TO EXECUTE UNDER STRESSFUL CONDITIONS	ADEQUATE	ADEQUATE	EXCELLENT

QUALITATIVE INDICATOR DEFINITIONS:

EXCELLENT - EXISTING RESEARCH SUGGESTS THAT THE SEARCH PATTERN POSSESSES THE SPECIFIED ATTRIBUTE TO A LARGE DEGREE

ADEQUATE - EXISTING RESEARCH SUGGESTS THAT THE SEARCH PATTERN POSSESSES ENOUGH OF THE SPECIFIED ATTRIBUTE TO REMAIN MARGINALLY EFFECTIVE

POOR - EXISTING RESEARCH SUGGESTS THAT THE SEARCH PATTERN DOES NOT POSSESS THE SPECIFIED ATTRIBUTE AND SEARCH EFFECTIVENESS MAY BE SUBSTANTIALLY IMPAIRED

displayed is a judgemental evaluation representing how well each of the search patterns satisfies any particular attribute.

Although qualitative indicators rendered are those of the author, they are based upon known and generally accepted results which have been published in relevant literature, including recent research and technical reports. These research results have been previously summarized in Chapter II.E and are presented in greater detail in Appendix C. Qualitative indicators adjudged in Table XXV follow directly from such research. However, indicators chosen for attributes #3 and #5 deserve special explanation.

It is important to recall that the experimental test in the MTS was conducted using a simulated stationary target. The degradation of horizon search effectiveness which appears to begin at 15 degrees and has become substantial by 25 degrees, obviously occurs due to the rapid decline in foveal (direct line-of-sight) acuity as the target moves into the upper periphery. However, research has also shown that the peripheral regions of the eye are very sensitive to target motion. Hence, a target located as much as 55 degrees off of direct line-of-sight may be completely invisible when stationary, yet easily detected when moving. These human visual characteristics were previously summarized in Figures 9 and 10.

These phenomena have practical relevance to the ground-to-air search task. Analysis of the threat previously revealed that hostile target density is highest at low

altitudes. Another characteristic of threat tactics is the distinction, in both altitude and speed, between attack helicopter tactics during close air support (CAS) missions and high performance ground attack aircraft (e.g., MIG-27 and SU-24) ingress profiles on battlefield and rear area interdiction missions. Although both are expected to be operating well below 500 meters, this region can be even further subdivided into an attack helicopter zone and a "fast mover" zone. Aircraft performing CAS will be using relatively slow speed nap-of-the-earth (NOE) navigation, popping up just high enough to obtain line-of-sight to the target, and remaining essentially stationary while launching and guiding, if necessary, its ordnance. Aircraft on interdiction missions will predictably be flying much faster, using terrain avoidance or terrain following navigation techniques which result in slightly higher operating altitudes than NOE. Hence, within this high threat density region (< 500 meters), as target altitude increases above NOE "tree top" level aircraft are likely to be moving increasingly faster due to this transition out of the CAS region and up into the fixed-wing interdiction region. From the ground observer's perspective, target relative motion increases with increasing target elevation.

Consequently, the actual effectiveness of the horizon search at higher target elevations is, no doubt, severely understated by MTS experimental results due to the complete

lack of target motion. Had MTS operational limitations not precluded controlled target motion there is little doubt that test results would reveal significantly improved effectiveness in the upper elevation (15 and 25 degrees) using the horizon search pattern. On the other hand, it is doubtful that either the lateral or vertical patterns would fare significantly better (relative to the horizon search) since their ineffectiveness at lower elevations was not distorted by the simulated stationary target. As previously discussed, the threat in this region consists predominately of relatively stationary targets (performing CAS missions) which, at maximum visual detection range, will be extremely difficult to observe without using direct foveal vision.

D. SUMMARY

Experimental test data definitely conforms to results anticipated from existing human visual search and detection knowledge. The three critical questions presented at the beginning of the chapter can now be answered and serve to summarize comparisons of relative effectiveness among the three alternative search patterns:

- "Experimental test results, summarized at Table XXIV, indicate that the horizon search provides both significantly greater detection probabilities and significantly lower detection times in high density threat regions. The vertical search appears to be the least effective search pattern overall and is virtually ineffective against near-horizon 'pop-up' type targets."

- "As displayed from a theoretical perspective at Table XXV, the horizon search possesses substantially greater quality as measured by those attributes deemed essential to an effective search."

- "Nearly 50 percent of the personnel tested prefer the horizon search due to its 'natural' pattern and greater perceived effectiveness in a combat situation. Personnel least prefer to use the vertical search and also regard it as the least effective search pattern."

VI. CONCLUSIONS

Conclusions derived from this research effort are expressed herein. These conclusions address the principle thesis objectives, previously specified in the Introduction:

- Generate and evaluate an alternative search and scan procedure for SHORAD weapons crews, and
- Incidental to such research, identify possible improvements in current training procedures.

It is anticipated that significant improvements in SHORAD visual search and detection performance will substantially increase overall SHORAD effectiveness on the modern battlefield.

A. SEARCH PATTERN EFFECTIVENESS

1. Analysis of critical factors bearing on the ground-to-air search task, including SHORAD weapons engagement capabilities, the tactical air threat, and human visual search phenomena, strongly suggests an alternative substantially different from the two existing search patterns. This alternative, referred to as the "horizon search" pattern, is a constant elevation scan, searching no more than 5 degrees above the horizon throughout the designated search sector.

2. Data generated from the REDEYE/STINGER Moving Target Simulator (MTS) experiment clearly indicate the superior

effectiveness of the horizon search. The horizon search produces a higher detection probability and requires less time to detect a target than existing search patterns within those regions where hostile aircraft density is greatest and poses the most immediate threat to combat maneuver forces and other assets SHORAD is responsible for defending. Additionally, experimental test results reveal the vertical search to be the least effective of the three patterns tested with particularly poor results against nap-of-the-earth (NOE) "pop-up" type targets.

3. Comparative analysis of the alternative patterns using search theory and existing human visual detection knowledge substantiates MTS experimental test results and further reinforces the superior effectiveness of the horizon search.

4. Despite the fact that test personnel had not previously used the horizon search (since it is not regarded as official doctrine and therefore does not appear in current field manuals) nearly half of those tested considered this search to be easier and also more effective than either of the existing search patterns. The vertical search was least preferred and considered least effective among the three search patterns.

B. TRAINING AND TRAINING PROCEDURES

1. Although age and experience of tested personnel do not appear to significantly effect visual search effectiveness,

MTS experimental data clearly indicates differences among different MOSes and reveals REDEYE personnel (16S) to be most effective. It is suggested that this significantly better REDEYE performance can be attributed to the routine MTS training that is peculiar to their MOS. Although REDEYE target tracking and engagement training in the MTS does not emphasize individual search and scan proficiency, personnel habitually use these search techniques during routinely conducted training sessions in the simulator. Existing research, although relatively limited in this particular area, suggests that search performance can be considerably improved through training. Search effectiveness appears to increase due to improvements in search sector coverage, peripheral acuity, and possibly foveal acuity [Ref. 1: pp. 110-116]. The significantly better performance attained by REDEYE personnel during the MTS experiment certainly corroborates such findings and further serves to reinforce the value of repetitious and periodic training in crucial combat related skills.

2. As previously noted, modifications to the existing projector arrangement in the simulator were necessary in order to simulate a stationary target. At the present time no provisions exist to simulate sufficiently realistic threat tactics that are likely to be encountered by SHORAD personnel. Specifically, aircraft film reels have not been developed that simulate helicopters performing NOE navigation techniques and "pop-up" tactics.

VII. RECOMMENDATIONS

Conclusions listed in the previous chapter elicit the following corresponding recommendations.

A. SEARCH PATTERN EFFECTIVENESS

1. The horizon search pattern should be adopted as the primary search and scan technique for SHORAD crewman, and other ground observers as well. It should be incorporated into applicable field manuals, advanced individual training, and unit training programs as expeditiously as possible.

2. The vertical search pattern should be discarded as an alternative search and scan technique, regardless of the previous recommendation's acceptance or rejection.

B. TRAINING AND TRAINING PROCEDURES

1. Serious consideration should be given to MTS simulator utilization for periodic (quarterly) search and scan training by ALL SHORAD weapons crews. Additionally, consideration should be given to simulator training on search and scan techniques for other non-SHORAD combat, combat support, and combat service support personnel. For example, a training period for such personnel might consist of an (annual) MTS classroom presentation on small arms for air defense (SAFAD), visual aircraft recognition (VACR), and search and scan procedures followed by familiarization training using search and scan techniques in the simulator.

The implementation of such a training program at unit level should be encouraged in applicable field manuals, emphasizing the significant improvement in target detection effectiveness that can be realized by SHORAD units in particular and all ground observers in general.

2. The following specific recommendations are offered for inclusion into design modifications currently being considered by U.S. Army Missile Command (MICOM) in the development of the Advanced Moving Target Simulator

a. Aircraft film reels should be developed and distributed which reflect current and near-future threat aircraft expected to be performing offensive air support (OAS) missions, especially close air support (CAS) and battlefield interdiction by ground attack aircraft. As a minimum, reels should be developed forthe SU-24 FENCER, SU-25 FROGFOOT, MI-8 HIP, and MI-24 HIND. Reels should also be developed which simulate friendly aircraft likely to be operating in SHORAD protected areas (e.g., AH-64 and A-10).

b. Film reels should present realistic attack profiles, such as very low altitude terrain avoidance techniques. It is <u>ABSOLUTELY IMPERATIVE</u> that films be developed to simulate attack/armed helicopters using nap-of-the-earth (NOE) and "pop-up" techniques.

c. A general review of aircraft film reels should be conducted with the goal of developing a package of simulator training reels which approximates, as closely as

technically feasible, anticipated threat aircraft and their corresponding tactics (refer to Appendix B for a general threat description. For classified threat information refer to the Threat Division, Directorate of Combat Developments, U.S. Army Air Defense School, Ft. Bliss, TX.). It is believed that these improvements will considerably enhance training realism and extract more of the training value potentially available in the Moving Target Simulator.

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APPENDIX A

SHOROAD WEAPONS

A. GUN SYSTEMS

1. VULCAN

The VULCAN Air Defense Gun System (VADS) fires 20mm high explosive rounds at rates of either 1000 or 3000 rounds per minute from its 6-barrel Gatling type cannon. It generates target range and range rate information from a pulse-doppler range-only-radar and supplies this to a gyroscopically stabilized optical sight which assists the gunner in correctly determining proper lead angle and superelevation. However, there is no automatic tracking capability and the gunner must manually slew and elevate the VADS to maintain the proper gun-target orientation. Cannon elevation and depression limits are +80 degrees to -8 degrees with full 360 degree turret rotation. The maximum effective range of the VADS against aerial targets is approximately 1.2 kilometers. The VADS exists in two versions: self-propelled used in armor and mechanized infantry divisions, and towed used in airborne, air assault, and infantry divisions. Both versions also have a ground fire capability. The VADS has a crew of four.

2. SGT YORK DIVAD Gun

The SGT YORK was recently developed as a replacement to the VADS. It uses twin 40mm Bofors guns, which fire

proximity or contact detonating rounds, mounted on an M-48 Tank chassis. Fire control functions can be accomplished automatically using an autonomous search-while-track radar for detection and IFF for electronic identification or using an optical sight and laser rangefinder in an electronic countermeasures (ECM) environment. It has a maximum effective range of 4 kilometers and can fire 360 degrees in azimuth with elevation and depression limits of +85 degrees to -10 degrees. SGT YORK is now in production and current plans are to replace the VADS with SGT YORK in AIM divisions in the very near future. The SGT YORK carries a crew of three.

B. MISSILE SYSTEMS

1. CHAPARRAL

The CHAPARRAL is a self-propelled guided missile system consisting of a missile launching station mounted on a modified cargo carrier chassis. The missile launching station contains a gunner's compartment and four launch rails for the MIM-72 guided missile which is a supersonic missile using passive infra-red (IR) detection, proportional navigation guidance, and a torque balanced control assembly. The MIM-72 is an adapted "Sidewinder" missile and, due to its IR homing, is often referred to as a "tail chase" weapon. However, the recent C Model missile provides a significant front-on capability due to increased IR sensitivity in the missile seeker section. The approximate maximum effective range is 5 kilometers. Although once

launched the missile is a "fire and forget" system, both target detection and identification must be accomplished visually. An additional 8 missiles can be stored in the carrier. The CHAPARRAL has a crew of five and is organic to the air defense battalion in armor, infantry, and mechanized (AIM) divisions.

2. REDEYE

REDEYE is a man-portable air defense system (MANPADS). It weighs 29 pounds and consists of a launcher, an IR seeking proportional navigation guided missile, and a battery coolant unit used to cool the missile seeker prior to launch. Although the system is relatively simple, rugged, and highly mobile, the engagement sequence consists of seven separate steps, each of which the gunner must perform rapidly and correctly. Hence, failure to detect a target as soon as it becomes visible can easily result in an engagement failure due to time compression of the gunner's engagement sequence beyond his capability to react before the target maneuvers out of the engagement envelope. Since REDEYE also uses an IR "tail chase" missile, with an approximate range of 3 kilometers, they are normally deployed well forward in the battle area. REDEYE Teams, consisting of two personnel both of whom can launch missiles, are distributed on the basis of one per company size unit to infantry, armor, and artillery battalions.

3. STINGER

STINGER is also a MANPADS, weighing 34.5 pounds, but has improved capabilities over REDEYE. Its approximate

maximum effective range is 4 kilometers. Due to an increased sensitivity of its IR seeker, the missile possesses a limited front-on capability which is ultimately dependent upon the IR source strength of the target. STINGER also has an integral IFF assembly to assist the gunner in target identification, however final identification is still made visually by the Team Chief. STINGER is now being deployed in active Army divisions, replacing REDEYE as the division's organic MANPADS capability.

APPENDIX B

THE THREAT: AN ANALYSIS OF SOVIET FRONTAL AVIATION

During the past decade, dramatic changes have occurred within the Soviet Air Force. In particular the most significant and radical transition has occurred within the Soviet tactical air force, Frontal Aviation (FA--Frontovaya Aviatsiya), and can be characterized as a fundamental switch from a defensive "air cover" oriented mission to a comprehensive and powerful offensive capability encompassing "air attack in all of its forms".

A. HISTORICAL DEVELOPMENT (1940-1970)

Although Soviet air support to ground troops has historically been the predominant mission for Soviet aviation, the means of implementing this mission have varied widely during the past 40 years. During World War II (the "Great Patriotic War") the Soviets were successful in the massing of air power for frontal air superiority, for the development of robust close air support aircraft, and for the development of a battlefield surveillance system [Ref. 1]. Unlike the U.S., which developed and refined strategic bombing as an instrument of warfare, the Soviet Union concentrated on using its air force to increase the striking power of its ground forces. Not only was the Soviet Air Force committed exclusively to ground support missions, but air armies, created in 1941, operated under the control of the Army

Front Commander [Ref. 2: pp. 5-6]. Hence within the framework of joint operations, the aifr force was used as "an extension of the ground commander's artillery". One of the failures of Soviet aviation during the war was its inability to consistently conduct in-depth penetrations behind the German lines to disrupt reinforcements, communications lines, and command, control, and logistics centers. Elimination of this particular deficiency has been a priority for Soviet planners in the past 15 years and, as will be seen, has resulted in tremendous quantitative and qualitative advances in FA assets. However, during the immediate post-war years and especially with the advent of the extensive U.S. nuclear bomber threat, Soviet aviation was designed and organized to conduct defensive air operations rather than ground attack missions. Nearly all of the first generation (design period 1946-1955) and second generation (1956-1965) aircraft built during this period were interceptors designed for the counter air mission. "As late as 1975, the basic fighter aircraft found in the frontal aviation armies were designed more for the interception of high altitude bombers than for ground support operations" [Ref. 2: p. 8].

B. ORGANIZATION

Soviet military aviation is organized into three separate forces:

1. Soviet Air Force (Voyenno vozdushnyye sily - VVS)
   - Frontal Aviation (Frontovaya aviatsiya - FA)
   - Long Range Aviation (Dal'nyaya aviatsiya - DA)

- Military Transport Aviation (Voyenno transportnaya aviatsiya - VTA)

2. Aviation of National Air Defense (Aviatsiya protivovozdushnor oboron strany - APV))
3. Soviet Navl Aviation (Aviatsiya voyenno morskogo flota - AVMF).

Figure B-1 depicts the organizational structure of the Soviet Armed Forces. FA, although under the administrative control of the Soviet Air Force in peacetime, consists of about 16 tactical air armies which are operationally subordinate to most of the 16 military districts within the Soviet Union and also to Groups of Soviet Forces outside the Soviet Union within the various Warsaw Pact nations (see Figure B-2). These military districts and Groups of Forces are operational commands roughly equivalent to the unified commands of the United States. Figure B-3 illustrates the composition of a typical Tactical Air Army. As noticeable from Figure B-3, triangular structure is typical although there exists considerable differences between various air armies dependent upon the perceived threat. For example, the 16th Air Army, which supports Groups of Soviet Forces Germany (GSFG) actually contains two corps with a total of 5 or 6 air divisions, whereas in every other instance divisions are directly subordinate to the Air Army headquarters. Also, the 16th Air Army contains more than 1000 tactical aircraft whereas the 17th, in Kiev Military District, contains only 100 [Ref. 3 : p. 219]. Presently, about three-quarters of the

combat strength of FA is deployed in Eastern Europe and the western military districts [Ref. 4: p. 15].

C. THE TRANSFORMATION AND MODERNIZATION OF FRONTAL AVIATION (1970-1982)

Frontal Aviation is the Soviet equivalent of our tactical air force and has consistently been the largest component of all the Soviet military aviation forces. As mentioned previously, dramatic and comprehensive changes characterize the transformation of FA within the past decade from a force "designed primarily to ensure local air superiority as a protective umbrella over Pact armies and their tactical and deep rear areas into a force capable of posing a truly major offensive threat to NATO ground forces and their intrastructure throughout the European theatre" [Ref. 5: p. 62]. This shift from a defensive counter-air to an offensive air attack capability is clearly commensurate with the Soviet view, no doubt precipitated by the NATO strategy of "flexible response", that a conventional initial phase of a war in Europe could be fought and won if combined ground/air forces could conduct deep, rapid penetrations along multiple axes of advance into Western Europe destroying NATO nuclear arsenals and launch sites by surprise, thus precluding NATO tactical nuclear retaliation while simultaneously insuring the absolutely vital high speed rate of advance necessary on an extended battlefield [Ref. 6: pp. 100-114 and 172-181]. This comprehensive modernization program

has, within the last decade, "transformed their tactical air force from one consisting mainly of limited range, low payload, day fighters into a potent, long range, tactical air army with increasing capability to operate in adverse weather. They are producing capable, modern tactical fighters at a rate more than double that of the United States" [Ref. 7: p. 57]. Figure B-4 depicts the increasing size and sustained growth of Soviet Frontal Aviation during the past 15 years. During the decade of the '70s the Soviets produced twice the number of fighter aircraft as the U.S. and are currently outproducing the U.S. by more than $2\frac{1}{2}$ to one. The production rate of the MIG-27 FLOGGER alone exceeds that of all U.S. fighter aircraft combined. As a result of high sustained production rates, the Soviets have been able to modernize their tactical air force to such an extent that two-thirds of FA consists of third generation (design period 1966-1975) aircraft, such as the MIG-27 FLOGGER and SU-24 FENCER, which are optimized for offensive air support (OAS) operations. As a result, the average age of their tactical aircraft is about $5\frac{1}{2}$ years, nearly 1/2 that of the U.S [Ref. 7: p. 57].

There has been a simulataneous and equally impressive improvement in the ground based, mobile air defense capabilities during the '70s. This concurrent buildup in tactical ground based air defense forces has enabled Frontal Aviation to shift its emphasis from the counter-air role to direct ground support operations without any loss in overall tactical air defense capability. Developments clearly

reveal that "there has been a radical change in functional concepts in recent years. The first priority (for FA) is no longer air defense, but rather air attack in all its forms" [Ref. 4: p. 17]. In addition to the sustained quantitative increases in FA aircraft since the early '70s, significant technological improvements have been made in aircraft design to support offensive air operations. Aircraft are now designed specifically for ground attack missions. Improved avionics (including terrain avoidance radar) and fire control systems (including laser designators and range finders), higher wing loading, and greater thrust-to-weight ratios characterize the third generation of air-craft and enable them to deliver, with vastly improved accuracy, much larger payloads (conventional and/or nuclear) over longer distances at high speeds and very low altitudes, thus avoiding or significantly delaying detection by NATO radar directed surface-to-air (SAM) systems (see Figure B-5).

Although their pilots apparently receive less training flight hours than their U.S. counterparts, FA in general is characterized by high operational readiness and a capacity for high sortie rates with low turnaroudn times:

> The Operational readiness status of Soviet FA units is on a permanently high level, and is continually improved and checked on by practice alerts. As part of these practice alerts, units are re-deployed from their bases to small auxiliary airfields, of which there are several hundred in frontal areas. This is made possible by the fact that combat aircraft are equipped with heavy duty landing gear using tire pressures of 7.0 to 9.0 atmospheres, gravity refuelling, systems, built-in engine starting equipment, and take-off aids in the form of JATO (jet assisted take-off) rockets.

> Another significant factor is the ability of the pilots to service their own aircraft. [Ref. 3: p. 197]

Due to the increased size and improved delivery capability of tactical FA, and also concurrent development of tactical air-to-surface missiles (TASM) systems with increasingly greater stand-off ranges, the net effect since the mid-1960s has been a ninefold increase in the weight of tactical (nuclear and conventional) ordnance that Soviet FA can deliver into NATO territory during offensive air operations [Ref. 9: p. 47].

The reconstitution of Frontal Aviation has also obviated earlier Soviet reliance on theater nuclear rocket strike and DA bomber strikes against NATO nuclear arsenals and delivery sites. Soviet operational concepts clearly distinguish between the effectiveness of nuclear and conventional fire support:

> Conventional artillery fire does not usually kill or destroy--it merely suppresses. Only nuclear fire destroys. In combating NATO nuclear means, the goal must be <u>destruction</u> or <u>seizure</u> (emphasis added). Suppressing, putting out of action, or pinning down are only temporary or holding actions pending the final resolution of <u>destruction</u> or <u>capture</u> (emphasis added). [Ref. 6: p. 82]

Current FA aircraft capabilities, which permit both conventional and nuclear payload deliveries, clearly provide for an extension of the ground commander's supporting fires well beyond tube artillery maximum range enabling suppression of targets which are desired to subsequently be <u>seized</u> intact. Additionally, nuclear arsenals and mobile delivery sites, such as LANCE and PERSHING II, can also be <u>destroyed</u>

with much greater certainty now due to the relatively invulnerable high speed, low-level flight capabilities permitted by advanced fire control systems coupled with terrain avoidance navigation systems.

Current FA missions and capabilities can thus be categorized as follows:

MISSIONS -

1. Conduct <u>independent air operations</u> to pre-empt, by neutralization or destruction; NATO rear area nuclear facilities and command and control centers in an effort to eliminate an immediate NATO nuclear retaliation capability thereby exerting reflexive control over NATO tactical options.
2. Establish early air superiority by conducting <u>offensive counter-air operations</u>, emphasizing suppression and elimination of NATO radar directed SAM systems, such as HAWK and PATRIOT, and air base attack against 2nd and 4th Allied Tactical Air Force (ATAF) airfields. The battlefield air defense mission is predominately accomplished by Soviet mobile ground based air defense, which is integral to all command levels from front to maneuver battalion [Ref. 10, pp. 18-39]. However, FA retains a significant air-to-air capability, including both look-down and shoot-down

capabilities on recently developed fourth generation aircraft.

3. Conduct offensive air support operations, emphasizing both battlefield air interdiction (BAI), by providing an extension to ground artillery in support of the commander's maneuver plan, and tactical air reconnaissance (TAR), by providing near real-time intelligence input for both immediate evaluation and inclusion into the Soviet automated troop control system (Automatizatsiya Upravleniya Voyskami - ASUV). FA also provides air support for "independent" forces, such as operational maneuver groups (OMG), airborne units, and air assault forces, operating autonomously on an extended battlefield.

CAPABILITIES -

1. FA consists of potent, long range, tactical aircraft optimized for ground attack and capable of conducting a large scale air attack against NATO air defenses, airfields, control systems, and nuclear facilities.
2. Current third generation aircraft are capable of carrying large conventional and/or nuclear payloads, including TASM with increasingly longer stand-off ranges, over long distances at high speed and extremely low altitude (well below 500 meters), thus avoiding detection by ground

based radar systems, and delivering payloads with great accuracy.

3. Aircraft are capable of high sortie rates and short turn around times, due to short take-off and landing (STOL) design features, rugged landing gear, and rapid refueling and rearming thus permitting ofrward basing and quick respon-siveness to air support requests.

D. THE ADVENT OF THE COMBAT HELICOPTERS (1974-1982)

Perhaps even more worrisome are the rapid advances made by the Soviets in helicopter warfare and the use of air assault forces. This past decade has witnessed a complete revolution in Soviet helicopter doctrine. The Soviets de-voted great attention to both U.S. use of heliborne forces in Vietnam as well as helicopter performance in the 1973 Mideast War. It is apparent that they now regard the heli-copter as a crucial element of combined arms operations in modern warfare. One of the most visible advocates of the helicopter in Soviet literature is Col. M. Belov. He regards future operations to be doomed to failure "unless mass use is made of helicopers" and has successfully aruged (as evi-denced by helicopter production rates and his subsequent promotion to Major General) that "the mass employment of helicopters is becoming an objective necessity in the tactics of land forces" [Ref. 11: p. 22]. The Soviets clearly re-gard the anti-tank capability of the helicopter as essential

to maintaining the momentum of offensive operations in modern armored warfare. As stated by Gen Reznichenko, a respected Soviet author:

> They are superior to other anti-tank weapons in terms of field of vision, maneuverability, and firepower. They are capable of hitting armored enemy targets while remaining out of reach of anti-aircraft weapons. The correlation between tank and helicopter losses is 12:1, or even 19:1 in the helicopter's favor, according to practical experiments. [Ref. 12: p. 21]

To complement an already substantial transport helicopter inventory, the MI-24 HIND attack helicopter was first introduced in 1974. By late 1977 Soviet military literature together with intelligence analysis of large scale Soviet training exercises conducted in 1976 and 1977 indicated that the HIND would be utilized in four major tactical missions:

1. Anti-armor operations: the HIND demonstrated its ability to take advantage of terrain to ambush armored vehicles and targets of opportunity during general ground support missions (Exercise KARPATY - '77)
2. Close Air Support: the Hind demonstrated an ability to function as "on call" fire support to repel counterattacks and also to eliminate pockets of resistance during offensive operations (Exercises SHIELD - '76 and KARPATY - '77)
3. Support of river crossing operations and heliborne assaults: the HIND capably functioned as a combined transport and assault helicopter by providing both

armed escort (accompaniment) and landing zone (LZ) suppressive fires for assault forces as well as transporting a squad size element on both air assault and river crossing operations (Exercises SEVER - '76 and KARPATY - '77)

4. Anti-helicopter operations: although not publicly discussed (until recently) it was clear that the Soviets were becoming concerned with the development of the U.S. Advanced Attack Helicopter (AAH) Program and were considering alternative weapons, such as radar-directed cannon and new air-to-air missiles, to combat this new threat.

By late 1977 it had become evident that this versatile and potent helicopter was quite capable of lending its mobility and firepower in close air support operations to ensure the rapid penetrations and fast moving theatre operations envisioned by Soviet planners [Ref. 13: pp. 32-33].

Today, over four years later, the MI-24 has demonstrated that it is not only an effective anti-armor weapon, but is itself capable of both functioning as a high-speed, nap-of-the-earth (NOE) "tank" and, with the adaptation of the S4-7 GRAIL IR seeking missile to an air launched configuration, also in an anti-helicopter role in air-to-air combat. Since its introduction in 1974 the HIND production rate has been phenomenal. Today, the total MI-24 inventory exceeds 1000 with a current production rate of more than 15 per month.

The rapid growth of the entire Soviet military helicopter force is reflected in Figure 7. The HIP-E, the most heavily armed helicopter in the world, is capable of carrying up to 192 57 mm unguided rockets and 4 AT-2 SWATTER homing anti-tank guided missiles (ATGM) with a maximum range greater than 2 miles. Designed initially as a transport helicopter, the HIP can also carry up to 32 troops. The HIND-D carries 4 SWATTER ATGMs, 128 57 mm rockets, and has a four-barrel Gatling type machine gun mounted in a nose turret. The HIND-E carries 4 AT-6 SPIRAL laser guided ATGMs with a range out to 6.2 miles. Both HIND models possess an all-weather sighting system, low light TV with a 5 mile range, laser range finder and can transport a squad size unit. The 1000 plus MI-24 attack helicopters and more than 1600 MI-8 HIP assault/transport helicopters together constitute the most formidable helicopter assault force in the world [Ref. 14: pp. 90-92].

The emphasis upon deep multiple axis of rapid advance and simultaneous destruction or seizure of critical air bases, command and control centers, and nuclear storage and delivery sites in the NATO rear is further manifested in the recent effort placed upon air assault operations. In addition to the one training and seven full-strength Soviet Airborne Divisions, there is now believed to be an air assault brigade for each front, consisting of a regiment of 64 HINDs, a squadron of new MI-26 heavy-lift helicopters, and three air assault rifle battalions. Additionally, each army now has

a helicopter transport regiment capable of lifting a normal motorized rifle regiment (MRR) and one of every three MRRs is receiving extensive air assault training [Ref. 15].

Rotary wing force missions and capabilities can thus be summarized as follows:

MISSIONS -

1. Ground support operations in direct support of the ground tactical commander, including:
   - anti-armor operations
   - anti-helicopter operations
   - "on call" CAS to conduct preparatory fires, repel enemy counterattacks, eliminate pockets of resistance, and engage targets of opportunity
   - troop transport across obstacles
   - security force operations, beyond the FLOT and on exposed flanks.
2. Air assault and transport operations, conducting independent operations to seize critical objectives in the enemy rear.

CAPABILITIES -

1. The MI-24 assists in supporting the high speed offensive by virtue of its mobility, lethality, and reduced vulnerability. It can accurately deliver tremendous firepower and is regarded as a high speed, NOE "tank".
2. Navigation and fire control systems permit NOE, all-weather flight and a capability to "pop-up"

and launch ATGM and rockets from long stand-off ranges, thus delaying and often completely avoiding detection altogether.*

3. The massive combined MI-24/MI-8 force permits multiple large air assault forces to be transported and supported well into enemy rear areas to disrupt and/or seize critical objectives.

E. COMMAND, CONTROL, AND COORDINATION PROBLEMS IN OFFENSIVE AIR SUPPORT OPERATIONS

The simultaneously developing events represented by the attack helicopter and the resurgence of the fixed-wing ground attack mission in FA necessitated closer coordination between ground and tactical air forces. The problems of effective joint air operations and airspace management, especially in the close air support arena, are complicated and often simply impossible to overcome in a fast moving, electronic warfare (EQ) environment. These problems, which involve battlefield airspace congested by friendly and enemy high performance aircraft, rockets, missiles, helicopters, air defense, and field artillery fires, are certainly not unique to the Warsaw Pact. They are also being addressed within the NATO alliance with various procedural and technical innovations being pursued to date without much success. As a result, "a considerable number of friendly aircraft are 'lost' to their

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*U.S. RED FLAG exercises have revealed that helicopters using "pop-up" attack techniques are spotted less than 40% of the time [Ref. 16: p. 54].

own ground based air defense systems in practically every major exercise" [Ref. 17: p. 94]. "In past NATO exercises, estimates have been made that 40% of the NATO aircraft destroyed were victims of friendly forces" [Ref. 2: p. 74]. A recent attempt within the U.S. air defense community to resolve the problem is the creation of the Joint Forward Area Air Defense (JFAAD) Task Force which is a test directorate operating directly for the Under Secretary of Defense for Research and Engineering. This task force has been charged with examining the procedural use of weapon systems, command and control systems, and operator tactics in an effort to improve U.S. airspace management capability, rather than developing new hardware requirements which would further automate existing command and control systems.

No doubt the Soviets recognize the extreme vulnerability of their reliance upon ground intercept controllers and air directing officers (avianovodchiki) in an ECM environment as well as the severe complications in airspace management that have arisen due to the rapid expansion of both air and ground based air defense assets. Soviet military press reports have indicated less than completely successful results in organizing coordination between air and ground forces, especially at lower levels where responsiveness is most acute. Major causes of their lack of success appear to include lack of an airborne FAC, an inflexible pre-planned fire support request system, and mutual lack of real-time information

between the aviator's knowledge of the ground tactical situation and the ground commander's knowledge of aviation asset availability and location [Ref. 18: p. 17].

As previously mentioned, NATO has also experienced difficulties with its tactical air control procedures. Fundamental differences exist between American and European perceptions of the concept of tactical air operations. Offensive air support (OAS) operations can be defined generically as air operations in direct support of armed forces operating on land. Components of OAS include (see NATO Tactical Air Doctrine Manual ATP-33):

1. Close Air Support (CAS)--Air missions which require detailed integration with the fire and movement of friendly ground forces and are directed against hostile targets located between the FLOT and Fire Support Coordination Line (FSCL). "CAS can make an immediate and direct contribution to the land battle."
2. Battlefield Air Interdiction (BAI)--Air missions flown in the battlefield area 80-100 km beyond the FSCL. Thus, although BAI supports the ground commander's tactical plan by engaging enemy rear area and/or second echelon forces, detailed integration is not required (similar to "armed reconnaissance").
3. Tactical Air Reconnaissance (TAR)--air missions which acquire intelligence information in the battlefield area.

RAF Wing Commander Jeremy G. Saye, in an Air University Review article, "Close Air Support in Modern Warfare", illuminates compelling reasons for NATO to re-examine its offensive air support missions. He states that CAS missions should be confined only to aircraft that can be immediately responsive to ground force mission needs, can conduct an effective attack by readily acquiring the target, and are survivable against Warsaw Pact SAM and AAA. By concluding that fixed wing aircraft (with the possible exceptions of only the AV-8 HARRIER and A-10 THUNDERBOLT II) do not have a forward basing capability with quick turn around capacity, do require target acquisition assistance from a FAC (which unrealistically implies an ECM free environment), and are extremely vulnerable to Soviet SAM and AAA, he essentially eliminates fixed wing aircraft as effective weapons in CAS and relegates the CAS role to the attack helicopter (perhaps supported by AV-8 and A-10 aircraft in JAAT operations). He convincingly argues that the appropriate mission for fixed wing attack aircraft is battlefield air interdiction (BAI) in the enemy rear area concentrating on interdiction of second tactical and successive echelons [Ref. 19]. What is significant about Commander Saye's article is that the Soviets seem not only to have reached the same conclusions but implemented his recommendations as well.

Soviet military authorities recognized in the late '70s that, with the immense firepower, mobility, and responsiveness available in the rapidly expanding helicopter force,

it was no longer feasible to concentrate high speed modern aircraft in a vulnerable CAS role in or near the FLOT. It was concluded that such operations would be wasteful. Henceforth, FA fixed wing aircraft "must be utilized in finding and destroying objectives deeper in the enemy's rear" [Ref. 18: p. 19]. Clearly, the profound impact of the "combat" helicopter (as it is often referred to in Soviet literature) has been to provide ground commanders with an extremely versatile and capable close air support weapon thus enabling fixed wing FA to concentrate predominantly on the BAI mission in NATO rear areas. Such a division of tactical resource effort optimizes the capabilities offered by both the rotary wing and fixed wing aviation assets of FA. A secondary, yet extremely significant advantage which accrues as a result of this division of effort and the forward basing capability of fixed wing FA aircraft is an alleviation of the airspace management and missile engagement zone (MEZ) coordination problems associated with returning to rear area airfields upon sortie completion.

F. RECENT TRENDS AND INDICATIONS

Although the transformation of Soviet FA from a defensive to an offensive air arm has been rapid and comprehensive there are clear indications that this transition is not entirely complete. Soviet plans for the air support of ground operations are still undergoing major revisions in organization and employment to more effectively support the primacy

of the ground offensive on an extended battlefield. The most significant of these recent changes is the decentralization of helicopter forces. Until recently all FA aviation assets, including attack and transport helicopters, were assigned to Tactical Air Armies subordinate to front (military district or group of forces) commanders. These rotary wing regiments have not been placed under the operational control of Army commanders and are now regarded as "Army Aviation" (Armeiskaia Aviatsiya) units. There is evidence that this decentralization is occurring down to division level with squadron size helicopter forces now under the tactical control of division commanders [Ref. 20: pp. 123-124]. This reorganization of helicopter forces more closely integrates helicopters into combined arms operations and increases responsiveness to their ground commander.

Advancements in the Soviet aviation technology field also continue unabated as fourth generation aircraft (design period 1976--present) are already entering into the operational forces, despite the fact that production of such third generation aircraft as the MIG-27 FLOGGER and SU-24 FENCER still continues at incredible rates. The newest generation of aircraft, encompassing the MIG-29 FULCRUM and SU-27 FLANKER (both with look-down shoot-down capability) air superiority fighters as well as a new variable-wing supersonic strategic bomber (BLACKJACK) that is larger than the U.S. B-1B, also includes the new SU-25 ground attack

aircraft, recently NATO code-designated FROGFOOT. This CAS aircraft, with its ten hardpoints for externally stored munitions and large caliber Gatling type gun, has the same long loiter, close support mission as the U.S A-10 THUNDERBOLT II although initial indications are that it possesses even better performance capabilities than its U.S. equivalent. The first operational SU-25 squadron was deployed to Afghanistan in 1982 and is now operating as a development unit to perfect techniques for coordin ting low altitude close support during joint air attack team (JAAT) operations with attack helicopters [Ref. 14: p. 36]. Additionally, a new heavy lift helicopter, the MI-26 HALO, is also in production now. Used to provide transport support to the new FA air assault brigades, the MI-26 is the heaviest helicopter currently in production anywhere in the world and, with its 22 ton payload lift capability, has a cargo similar in payload and size to the U.S. C-130 HERCULES tactical transport turboprop [Ref. 14: p. 91]. The Soviets are expected to soon deploy a new helicopter which has been designed specifically to combat the helicopter threat [Ref. 21: p. 1186].

The push for military technological advancement to improve the "qualitative correlation of forces" will no doubt continue to receive priority as indicated in a recently released study by the White House Office of Science and Technology Policy:

> ...nine Soviet research institutes working with the eight design bureaus under centralized direction continue to significantly improve existing production aircraft and a range of new aircraft concepts... [Ref. 9: p. 47]

G. SOVIET TACTICAL AIR THREAT SUMMARY

The following major points summarize the transformation of FA units into an offensive air support force, and the current status of the modernization effort implemented during the past decade:

- Soviet FA has been transformed from a numerically inferior defense oriented fighter/interceptor force consisting of limited range, low payload, day fighters into a numerically superior force of potent, long range, tactical aircraft capable of "air attack in all its forms" with an increasing capability to operate in adverse weather.
- Employment doctrine is aimed at achieving air supremacy through conventional pre-emptive air operations including a massive coordinated air attack against NATO air defenses, airfields, control centers, and mobile as well as fixed nuclear capable targets.
- An extensive and simultaneous buildup of mobile ground based SAM systems has relieved FA of its air defense role and enabled it to concentrate on optimizing for OAS operations.
- Due to their mobility, large lead capacity powerful armament, lower vulnerability, better responsiveness,

and longer loiter capability, combat helicopters now perform the CAS mission, thus releasing fixed wing FA for BAI where it can be better utilized as an extension of artillery on an extended battlefield.

- Recently, helicopter forces have been detached from FA Tactical Air Armies and subsequently reorganized into Army Aviation Units as an integral air arm consisting of combat helicopters functioning as full fledged members of a combined arms force conducting high speed offensive operations.
- Tactics to accomplish OAS operations all demand low level flight to avoid radar detection, with fixed wing ground attack aircraft concentrating on high speed, low level penetrations to conduct BAI missions, and rotary wing emphasis upon NOE navigation and short exposure "pop-up" techniques for ordnance delivery. Emphasis upon the advantages offered by low level flight, capitalizing especially upon terrain meshing from both forward area radar (FAAR) and visual detection as well as long range acquisition radars, is reflected in Soviet training manuals used for instruction in FA schools [Ref. 22: pp. 125-128]. This low-level flight emphasis is further portrayed graphically at Figure B-7.

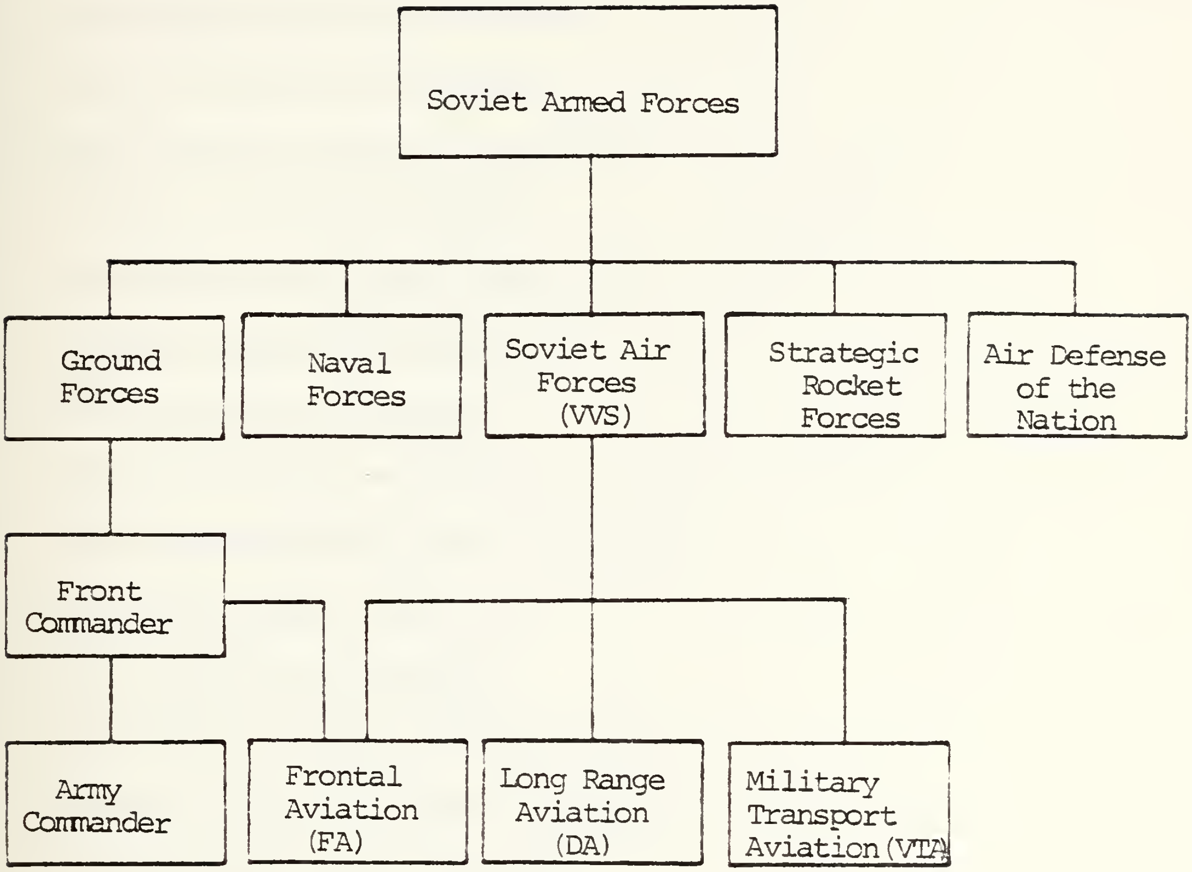


Figure B-1. Soviet Armed Forces Organization

Group of Soviet Forces in Germany

Northern Group of Forces (Poland)

Central Group of Forces (Czechoslovakia)

Southern Group of Forces (Hungary)

Leningrad Military Distict

Baltic Military District

Belorussian Military District

Moscow Military District

Carpathian Military District

Odessa Military District

Kiev Military District

North Caucasus Military District

Transcaucasus Military District

Volga Military District

Ural Military District

Turkestan Military District

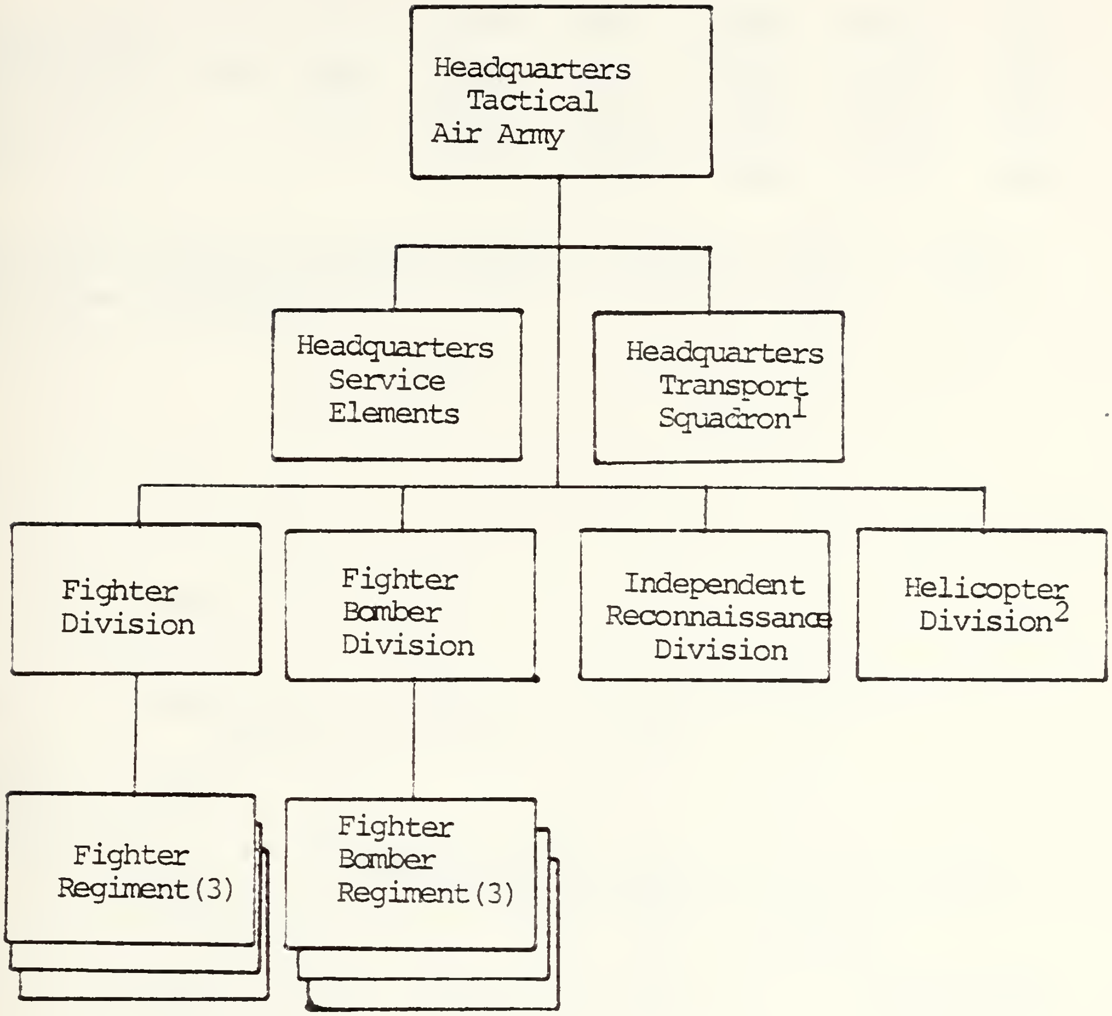
Central Asian Military District

Siberian Military District

Transbaykal Military District

Far Eastern Military District

Figure B-2. Soviet Military Districts and Groups of Forces



1: Attached from Military Transport Aviation (VTA)

2: Recently reorganized and reassigned to Ground Forces as "Army Aviation"

Figure B-3. Soviet Tactical Air Army

FRONTAL AVIATION INVENTORY

	1977	1978	1979	1980	1981	1982
TOTAL A/C*	4600	4580	4650	4566	5000	5300
FIGHTER/GRND ATK	3810	3865	3890	3550	4385	4350
MIG 23/27	700	1100	1300	1400	1300	1800
SU-24		120	190	230	370	480

*Includes Fighter/Ground Attack, Reconnaissance, & ECM; Excludes Helicopters

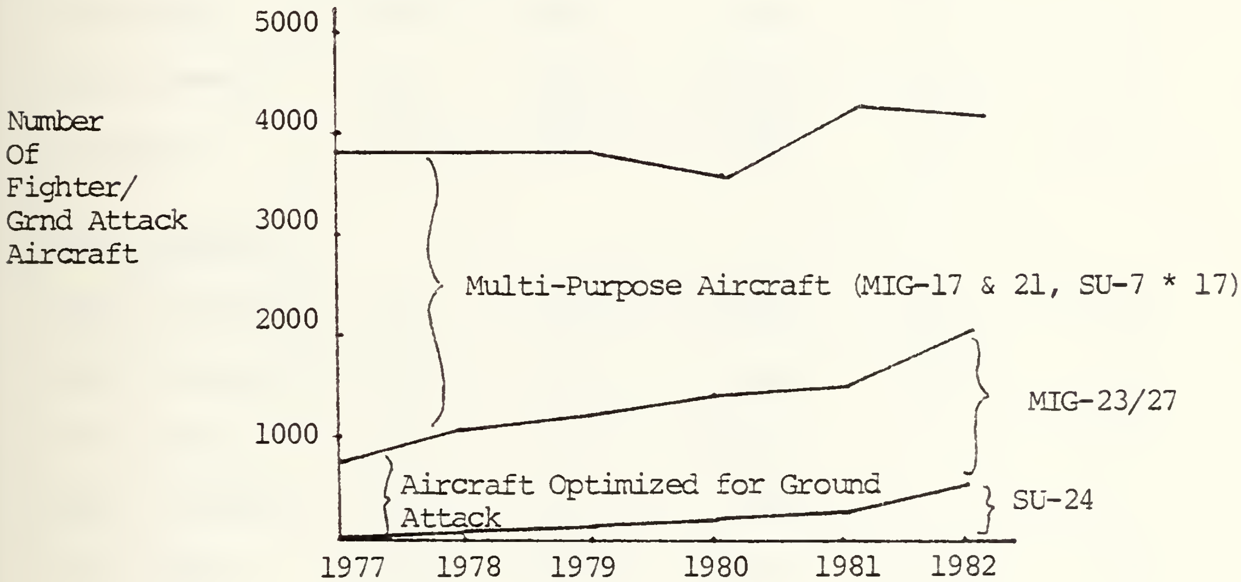


Figure B-4. Frontal Aviation Inventory

Design Generation And Aircraft	Ordnance load (tons)	Maximum combat radius (miles)	Offensive load carrying capacity	External ordnance stations	Maximum speed (Mach number)
First (1946-55)					
IL-28 Beagle	2.2	600	1,320	3.0	0.80
MIG-15 Fagot	0.5	280	140	2.0	0.87
MIG-17 Fresco	0.5	360	180	2.0	0.96
MIG-18 Farmer	0.5	400	200	2.0	1.35
Average	0.9	410	460	2.3	n.a.
Second (1956-65)					
MIG-21 Fishbed D	1.0	200	200	2.0	2.00
SU-7 Fitter	2.0	300	600	6.0	2.00
YAK-28 Brewer	2.2	500	1,100	3.0	1.10
Average	1.7	333	633	3.7	n.a.
Third (1965-75)					
MIG-23 Flogger B	2.2	525	1,155	5.0	2.30
MIG-27 FLogger D	2.2	600	1,320	7.0	1.60
SU-17 Fitter C	3.0	600	1,800	8.0	1.60
MIG-21 Fishbed J	1.0	400	400	5.0	2.10
SU-19 Fencer	5.0	800	4,000	6.0	2.30
Average	2.7	585	1,735	6.2	n.a.

Figure B-5. Frontal Aviation Capability [Ref. 2 : p. 32]

HELICOPTER INVENTORY

	1977	1978	1979	1980	1981	1982
Total	470	612	3700	3460	3200	3500
MI-8 HIP	-	161	1660	1470	1600	1600
MI-24 HIND	-	31	310	580	750	950

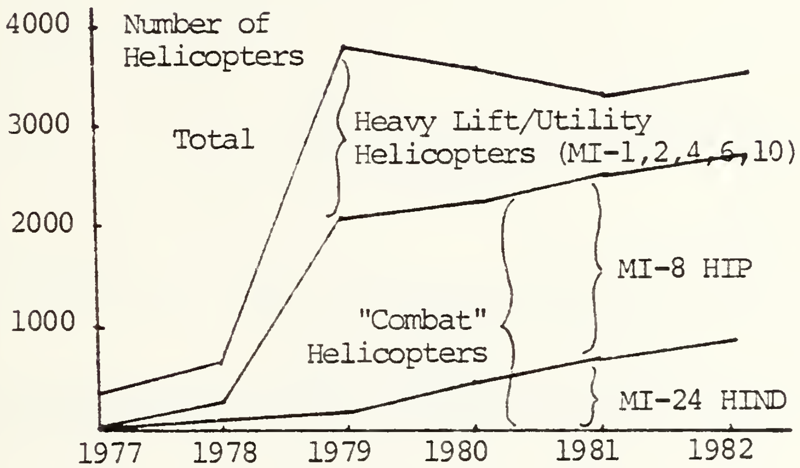


Figure B-6. Soviet Helicopter Inventory

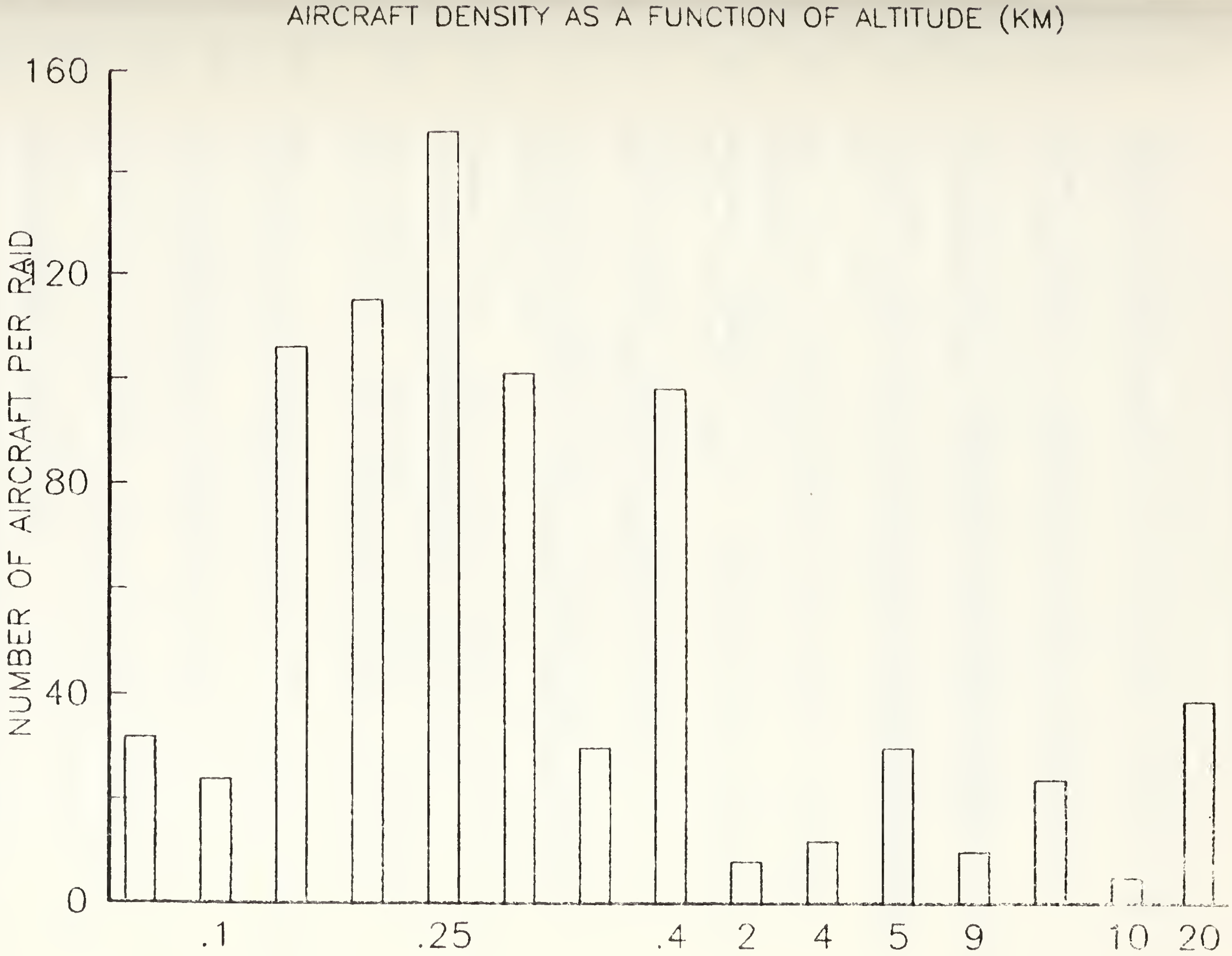


Figure B-7. Threat Aircraft Density Source: Studies and Analysis Division, Directorate of Combat Developments, U.S. Army Air Defense School

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APPENDIX C

VISUAL SEARCH AND DETECTION FACTORS

The purpose of this appendix is to document the generalized summary of results presented in Chapter 2, paragraph E. The human visual detection process can be divided into three essential elements as follows:

1. Original visible elctromagnetic energy reflected off or emitted from the target source,
2. Attenuation of reflected energy due to the intervening media between original source and receptor, and
3. Incident energy received by photoreceptors and processed by the brain.

As in any elementary communications process these elements can be easily represented in model form as presented in Figure C-1.

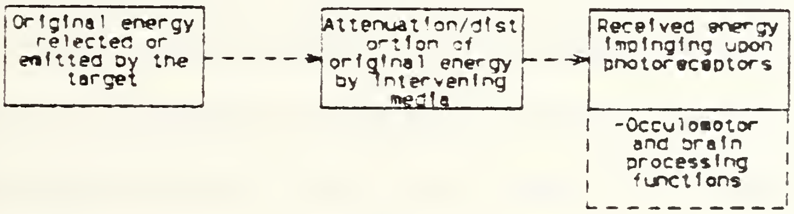

Figure C-1. Vision Model

This appendix will document various research findings which contribute to the three major elements of the visual detection process.

A. TARGET FACTORS

1. Size

The monumental work, involving some 450,000 responses, on developing contrast thresholds of the human eye, published in 1946 by H. R. Blackwell, found that target size necessary for detection decreases as overall luminance increases. Thus, larger targets require less overall contrast for threshold detection [Ref. 1]. This finding was substantiated throughout the Human Resources Research Organization's (HumRRO) tests conducted in the 1960s. These tests, along with a Human Engineering Laboratories (HEL) test conducted in 1959, all showed that target size definitely affects range of target detection [Ref. 2,3,4,5]. Both target altitude and range together determine the actual slant range, or line-of-sight distance from the observer to the aircraft. Field tests by Hoffman and Buell found that targets approaching at higher altitudes were detected at greater ranges [Ref. 6: p. 16]. This result occurs as a consequence of decreasing atmospheric turbidity at higher elevation angles and will be discussed further in the next section. Recent tests conducted to assess ground observer ability to detect low flying helicopters also show that detection probability decreases with increasing target range [Ref. 7].

2. Shape

In general shape has been found to be an unimportant parameter for detection of small targets [Ref. 8]. One study suggests, however, that as targets become narrower and longer, they become more difficult to detect [Ref. 9].

3. Luminance

Target luminance is the property which largely determines contrast and, as a result, target detectability. Target luminance consists of the product of surface luminance multiplied by the target directional refectance factor [Ref. 10: p. 14]. If all other conditions are held constant, an increase in target luminance (assuming original target luminance to be greater than background luminosity) will increase contrast thus increasing detection probability. It has been suggested by Koomen that the contrast of most aircraft probably hovers near zero, although it may range up to 5.0 [Ref. 11]. Various techniques are currently being pursued in the area of optical contrast reduction. For example, target contrast and refectance can be reduced by light absorbant surface coatings. A recently field tested development consists of launching a red phosphorous aerosol from the aircraft as a countermeasure to visual detection [Ref. 12].

4. Color

In addition to luminosity contrast, color contrast between target and background also influences target detection.

Studies have generally shown that yellow/orange and blue/green targets are more readily detectable, with green showing reduced detectability, and extreme blue and red targets tending to be the most difficult to detect against a neutral background [Ref. 13: pp. 69-70]. Color discrimination varies among individuals, however the influence of color on detection is directly attributable to occular spectral sensitivity which, for most people, exhibits greatest responsiveness in yellow through green wavelengths [Ref. 14: p. 44]. Background color also influences color contrast and will be discussed in the next section. Color contrast has been found to be the primary reason for detection of helicopters approximately 10 percent of the time [Ref. 7: pp. F-4 and F-5].

5. Target Motion

Dynamic visual acuity (DVA) is a measure of how well the eye can perceive detail (i.e., visual resolution) on a target that is moving. DVA does not substantially deteriorateuntil target movement rates exceed 60 degrees per second [Ref. 14: p. 47]. Even for fatigued personnel DVA does not begin to deteriorate until targets exceed 40 degrees per second [Ref. 15]. Obviously targets of concern in the ground-to-air search task are not likely to approach these relative velocity limits unless they are extremely close to the observer. Field tests have shown that targets exhibiting minor relative motion are more readily detected

than targets exhibiting little or no motion. Hence, for a given range, a crossing target exhibiting some tangential velocity is more easily detected than a head-on target exhibiting closing, but no tangential, velocity [Ref. 5]. In fact, target motion is extremely important in the detection process and will be further discussed in Section C.

6. Collateral Effects

The HumRRO tests in 1965 consistently found that jet aircraft were visible at greater distances than prop aircraft. Additionally, aircraft on crossing patterns were detected at greater ranges than those using head-on courses. These results were attributed to greater exhaust fume densities for jet aircraft as opposed to prop aircraft [Ref. 5: p. 12]. Considerable interest in exhaust detection prompted the development of an engine smoke prediction model for the purpose of examining exhaust detectability in the visual spectrum [Ref. 16]. Such concern also served to motivate development of smokeless engines, both for aircraft and gound launched missile systems. Field tests performed to determine ground observer effectiveness in detecting helicopters (HAT, AUDIT, HONEST II, and HELORADE which were all conducted by CDEC) have shown that several collateral dues, listed below, serve as the primary reason for detection in 20 percent of the cases [Ref. 7: pp. F-4 and F-5):

Glint - 8.9%

Rotor flicker - 7.5%

Sound - 2.5%

Dust - .5%

Other - .9%

Total - 20.3%

The above list pertains to helicopters navigating crossing courses in front of the ground observers. The primary detection cue for helicopters using "pop-up" tactics was found in another field test (TAHOE by CDEC) to be rotor flicker [Ref. 5: p. F-4].

B. ENVIRONMENTAL FACTORS

As previously mentioned, the original energy reflected or emitted by the target stimulus will ordinarily be mitigated in some manner, usually distorted or diminished, as a result of the intervening media between the target and the observer.

1. Background

Background luminosity and chromaticity largely determine detection through target contrast as discussed earlier in Chapter 2, paragraph E. "It is generally agreed that local target contrast is the most critical objective factor in the target acquisition process" [Ref. 10: p. 17]. During typical daylight viewing conditions most aircraft appear as black (or dark) objects on a lighter (usually

blue or grey) background. Thus, as intuitively expected, field tests performed by Hoffman found increasing reduction in aircraft detection range at the onset of twilight [Ref. 6: p. 18]. Overington, in his work for the Guided Weapons Division of British Aircraft Corporation, also found conclusively that, for neutral targets at realistic ranges, there is a significant difference in detection between aircraft against grey and blue sky backgrounds at equal luminosity [Ref. 13: p. 70].

2. Structure

Generally, structure in the visual field (as opposed to an unstructured, or "empty" field), appears to aid the observer in systematically covering the area to be searched. Nonetheless, too much structure appears to induce excessive "noise" and cause problems in target discrimination. However it has been recognized that a systematic scanning procedure, induced by a structured field, should contribute to improved detection [Ref. 10: pp. 97 and 103].

3. Atmospherics

The use of "apparent" contrast indicates that the attenuating effects of atmospherics have been taken into consideration and that the contrast is being computed at the observer's position [Ref. 17: p. 279]. When viewing over long distances, prevailing meteorological conditions can significantly modify target contrast as a function of

range. Generally, two phenomena account for such contrast modification:

1. Atmospheric attenuation which reduces target contrast as a consequence of light scattering by particles and light absorption by suspended moisture droplets (turbidity), and

2. Atmospheric turbulence, which causes such effects as "shimmering" of objects near the surface on a hot day, is a consequence of local atmospheric refraction due to wind shear and convective heating from the ground [Ref. 13: pp. 257-328].

Equations presented in Chapter 2.E were derived from empirical data collected by Middleton and reveal contrast to be an exponentially decreasing function of range with rate of decrease dependent upon local meteorological sighting range defined as 2 percent atmospheric contrast transmittance [Ref. 18]. These two phenomena together determine effective slant path visibility which, as a consequence of the usual tendency for meteorological sighting rante to increase with increasing altitude (reduction of near surface turbulence and decreased moisture and particle content at higher altitudes), tend to yield longer detection ranges for aircraft at increasingly higher elevation angles [Ref. 13: pp. 330-331].

4. Glare

Glare within the visual field can significantly reduce visual effectiveness depending upon its intensity

and location within the field of view. It is defined as "a source of luminance within the visual field that is sufficiently greater than the luminance level to which the eyes are adapted to cause reduced performance" [Ref. 10: p. 21]. Studies and field tests have examined the effect of glare from various angular positions within the visual field of view. Results show decreasing visual effectiveness as the glare source gets closer to line-of-sight [Ref. 19]. Field test results from Hoffman and Buell also indicate significant reduction in target detection ranges as the sun-observer-target angle becomes increasingly smaller [Ref. 6 : p. 16].

C. HUMAN VISUAL CAPABILITY

Acuity and visual performance among individuals tend to exhibit large variances. Significant research has focused upon understanding the functions of the eye as well as mapping the overall visual effectiveness of the human visual system, including its optics, occulomotor functions, photoreceptor quality, and neural network systems which couple the eye to the brain.

1. Photoreceptors

Diagrams of the eye and photoreceptor density were presented in Chapter 2. As previously discussed, cone photoreceptors are concentrated exclusively within a very small region at the base of the retinal wall known as the

fovea. They are predominantly used for daylight vision and are of four or five spectral sensitivities thus providing the basis for color vision. Rod photoreceptors, used predominately for night vision, are located throughout the remainder of the retinal wall with greatest density at about 20 degrees eccentricity from the central fovea. The fovea itself is completely free of rods. Between the retinal photoreceptors and the optic nerves, which transmit visual images as pulse discharges to the two visual cortexes of the brain, are a series of neural networks consisting of neurons, axions, and ganglion cells. Pulse discharges pass through these networks which contain complex interactions and feedback loops that function as differentiators and integrators of signals received from the photoreceptors [Ref. 13: pp. 7-16].

2. <u>Occulomotor Functions</u>

During normal vision the eyeball is actually in a state of continual motion. The most significant early study performed to determine the characteristics of eye movement was that of Ford et al. in 1959. Their experiment actually measured the rate and distance of eye movement in between periods of eye stability. They found that the eyes continually adjust the focal, or fixation, point and that such adjustments, referred to as saccadic motion, normally occur about three times a second during a free search task.

Also measured was actual fixation time which usually lasted slightly longer than .25 seconds [Ref. 20]. It now appears to be generally accepted that saccadic movements comprise about 15 percent of the time spent during free search. More recent research shows that saccadic motion actually consists of three different types of eye movement that occur in between successive fixations. These are referred to as "tremor", which is regarded as "the necessary residual oscillation due to muscular imbalance so that muscles controlling voluntary eye movements won't seize up", "intersaccadic drift", believed due to "residual muscular imbalance", and the saccades, which are attempts to correct or adjust the fixation point [Ref. 13: p. 22]. Recently, dynamics between head, body, and eye movements have been studied to determine the effect of compensating and coordinating mechanisms among the three [Ref. 21].

3. Search Area

Individual fields of view vary due to differences in peripheral acuity. However, it has been found that search time varies directly with the angular range over which the subject must search [Ref. 22]. A general conclusion for search in structured fields is the tendency to scan larger areas with larger interfixation (saccadic) distances than smaller areas, but not so rapidly as to cover the larger area in the same amount of time [Ref. 23: p. 10]. The

HumRRo field tests clearly showed that search sector size significantly effected range of aircraft detection. Search sectors of 5 degrees resulted in a mean aircraft detection range of 12 kilometers, whereas sectors greater than 180 degrees resulted in a mean detection range of less than 2 kilometers [Ref. 5]. Such results clearly demonstrate the value of accurate directional cueing information in the ground-to-air search task.

4. Target Motion

Often the initial reaction to focus search effort in any particular region is prompted by target motion. Although direct foveal acuity, which enables critical high-resolution vision, deteriorates rapidly as the target recedes from direct line-of-sight focus it is now well established that the peripheral regions of the retina are extremely powerful in detecting off-axis target motion. A general finding is that, as the target recedes away from the fovea, detection of mtion requires increasingly greater target velocity. However, the capacity to detect motion remains relatively great out to at least 55 degrees eccentricity [Ref. 13: p. 69]. Research reveals that significant differences exist between detection of moving and stationary targets. For targets exhibiting motion out to at least 55 degrees, "there is no significant change in sensitivity for the peripheral image compared to the foveal image. For the stationary case, peripheral detection requires more

than a four-fold increase in contrast over that required for foveal detection" [Ref. 24: p. 203]. These ideas are graphically illustrated in Chapter 2.E.

5. Accommodation and Empty Field Myopia

In a relaxed state the eyes tend to focus at a point less than one meter away. For most people, this naturally induced myopic condition occurs within one minute in the absence of other voluntary attempts to focus elsewhere. This condition, referred to as "empty field myopia", can occur as a result of prolonged exposure to an empty, structureless field (such as a cloudless sky) and causes a failure of the perceptual mechanism leading to temporary loss of critical vision [Ref. 10: p. 46]. Attempts to eliminate the effects of empty field myopia have been pursued by Whiteside and Matthews et al. Whiteside noted that visual defocus can be corrected by introducing a stimulus within the field of view that can be focused. The effectiveness of such a stimulus is dependent upon its proximity to line-of-sight. A stimulus placed beyond 5 degrees appears to have lost all effectiveness whereas one placed with 2 degrees of line-of-sight reverses involuntary defocus [Ref. 25]. Matthews et al. have discovered that "an accommodative aid located at optical infinity improves detection by as much as 30 percent over empty field performance" [Ref. 26: p. 733].

6. Workload and Stress Effects

Little is known about the effects of stress and anxiety on human visual processes [Ref. 10: p. 128]. Increasing motivation appears to initially improve performance in pressure situations, although further increases cause reduced performance [Ref. 15: p. 59]. Experimental data suggests that peripheral vision is reduced under conditions of observer stress [Ref. 27]. Smoking appears to first stimulate but then depress visual accommodation [Ref. 28: p. 30-36].

7. Optical Aids

Both the early HumRRO studies and the recent helicopter acquisition tests reinforce the currently adopted procedure to use binoculars strictly as an aid in identifying and recognizing aircraft (VACR) once they are detected. However, relying upon unaided vision, with its greater field of view, has consistently appeared to be the most effective means of target detection [Ref. 5 and Ref. 7: p. C-17].

8. Training Effects

The HumRRO tests revealed that training or experience in a particular field situation tend to improve detection performance even after only one day of practice [Ref. 5]. The VPI report concludes that "training techniques show promise to improve peripheral acuity, possibly improve

foveal acuity, improve DVA, and improve search uniformity of coverage" [Ref. 10: p. 116]. The report further suggests a recommended research program with highest priority given to search techniques and training as the most promising methods of improving human visual search performance [Ref. 10 : p. 127].

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APPENDIX D

EXPERIMENTAL DATA AND STATISTICAL TESTS

The purpose of this appendix is to:

1. Document technical data pertaining to the MTS experiment,
2. Provide a detailed explanation of statistical analysis methodology, and
3. Illustrate specific statistical tests used and results obtained.

A. TECHNICAL DATA

MTS simulator illumination and intensity controls were adjusted to approximate an aircraft at maximum detection range under clear daylight conditions. Specific rheostat settings used were as follows:

- Background Control: 95% illumination
- Foot Control: 95% illumination
- IR "Dot" Intensity: 28% [Ref. 1]

B. MASTER DATA COLLECTION SHEETS

Original test design information (e.g., troop #, search pattern, elevation angle, etc.) was transferred to individual data sheets to aid the controller during the conduct of the experiment. Upon test completion, data was collected from individual data sheets to facilitate statistical analysis.

C. STATISTICAL ANALYSIS LOGIC

A statistical analysis methodology was selected which permitted use of either parametric or nonparametric statistical tests, as appropriate. This methodology, which was developed to compare search pattern effectiveness, is presented in flow diagram form in Figures D-1 through D-5.

D. STATISTICAL TEST RESULTS

1. ANOVA Assumptions

The test design permitted use of parametric two-way ANOVA (7 observations per cell) to examine possible differences in mean time to target detection among search patterns. However, the following assumptions, which ANOVA requires when testing for possible differences among the search patterns (i.e., "pure" row effects), were not sufficiently met:

- Normality of underlying distributions (of target detection times),
- Constant variance among distributions, and
- Additivity of row (search pattern) and column (elevation angle) factors in the linear ANOVA model [Ref. 2; 3, pp. 681-682; and 4].

Consequently, appropriate nonparametric tests were used to perform subsequent hypotheses testing. Unless specified otherwise, all significance levels are .05.

2. Statistical Tests in Support of Primary Objectives

a. Probability of Detection (MOE #1):

(1) Confidence Intervals (Refer to Tables VII and VIII)

95% confidence interval lower (L) and upper (U) limits obtained from Table A4 (Binomial Sampling Table), Ref. 5, where:

$$P(L \leq p \leq U) \quad 1 - 2\alpha \quad = \quad .95$$

(2) Statistical Significance Between Detection Probabilities

TEST: DIFFERENCE OF PROPORTIONS [Ref. 3, p. 552-554]

H_0: $P_i = P_j$; $\forall\, i \neq j$ at elevation (e) and search region (e)

H_1: $P_i \neq P_j$; $\forall\, i \neq j$ at elevation (e) and search region (e)

TEST STATISTIC:

$$TS = \frac{|P_i - P_j|}{\hat{\sigma}}$$

where

$$\hat{\sigma} = \sqrt{\hat{P}(1-\hat{P})\left(\frac{1}{n_i} + \frac{1}{n_j}\right)} \quad , \quad \text{and}$$

$$\hat{P} = \frac{n_i P_i + n_j P_j}{n_i + n_j}$$

REJECTION REGION: Reject H_0 if $TS > Z_{(\alpha/2=.025)}$

TEST RESULTS: See Tables VII and VIII

b. Time to Detection (MOE #2):

(1) Use contingency table analysis to test for independence between search pattern type and elevation angle

TEST: χ^2 TEST FOR INDEPENDENCE [Ref. 5, p. 158-162]

H_0: P(row i, column j) = P(row i) · P(column j), $\forall i,j$

H_1: P(row i, column j) $\neq$ P(row i) · P(column j) for some i,j

TEST STATISTIC:

$$TS = \sum_{i=1}^{c} \sum_{j=1}^{r} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

REJECTION REGION: Reject H_0 if TS > $\chi^2_{df=(r-1)(c-1)}$

TEST RESULTS:

(cells are number of detection times less than the grand mean)

		ELEVATION ANGLE (DEGREES)			
		<1	5	15	25
Search Pattern	LAT	5	9	10	17
	VERT	5	10	15	14
	HOR	15	16	7	6

TS = 18.5; df=6

Therefore, reject H_0 since TS = 18.5 > χ^2_6 = 12.59.

(2) Graphically examine distributions

Histograms are provided at Tables XXVI through XXXII.

(3) Determine if there are differences between search pattern detection time distributions at specific elevations and regions (Refer to Tables XVIII and XIX).

TEST: BIRNBAUM-HALL 3-SAMPLE SMIRNOV TEST

[Ref. 5: p. 377-379]

H_0: $F_1(x)$, $F_2(x)$, $F_3(x)$ are identical distributions

H_1: At least two of the distributions are different

TEST STATISTIC: $TS = \sup_{x,i,j} |s_i(x) - s_j(x)|$

REJECTION REGION: Reject H_0 if $TS > W_{1-\alpha}$ quantile in Table A22.

TEST RESULTS:

	TARGET ELEVATIONS (DEGREES)				SEARCH REGIONS (DEGREES)			
	<1	5	15	25	<1	≤5	≤15	≤25
LAT-VERT	.22	.17	.26	.24	.22	.14	.13	.09
VERT-HOR	.46	.32	.25	.35	.46	.36	.14	.10
LAT-HOR	.49	.38	.36	.50	.49	.40	.24	.12
LARGEST VAL.	.49	.38	.36	.50	.49	.40	.24	.12
n	21	21	21	21	21	42	63	84
RR(α=.05)	.43	.43	.43	.43	.43	.33	.30	.26
REJECT H_0?	YES	NO	NO	YES	YES	YES	NO	NO

(4) Determine if there are differences among Q_{50}, Q_{75}, and Q_{90} between the search patterns at specific elevations and also within search regions (Refer to Tables XVIII and XIX).

TEST: QUANTILE TEST [Ref. 5: p. 171-176]

H_0: All three search patterns have the same Q_{50} (repeat for Q_{75} and Q_{90})

H_1: At least two of the search patterns have different medians (repeat for Q_{75} and Q_{90})

TEST STATISTIC:

$$TS = \sum_{i=1}^{c} \sum_{j=1}^{r} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

REJECTION REGION: Reject H_0 if $TS > \chi^2_{df=c-1} = 5.991$

TEST RESULTS:

Target Elevations

		Q_{50}				Q_{75}				Q_{90}		
		LAT	VERT	HOR		LAT	VERT	HOR		LAT	VERT	HOR
5 DEGREES	<	9	8	14	<	15	13	18	<	16	18	21
	≥	12	12	7	≥	6	7	3	≥	5	2	0
TS			3.562				2.423				5.992	
REJECT H_0?/P			NO				NO				YES/P<.05	
15 DEGREES	<	9	14	8	<	16	17	12	<	18	19	17
	≥	11	7	12	≥	4	4	8	≥	2	2	3
TS			3.318				2.921				.366	
REJECT H_0?/P			NO				NO				NO	

Search Regions

		Q_{50}				Q_{75}				Q_{90}		
		LAT	VERT	HOR		LAT	VERT	HOR		LAT	VERT	HOR
≤ 15 DEGREES	<	23	29	42	<	44	40	50	<	53	49	59
	$\geq$	36	29	20	$\geq$	15	18	12	$\geq$	6	9	3
TS			10.244				2.176				3.779	
REJECT H_0?/P			YES/P<.01				NO				NO	
≤ 25 DEGREES	<	39	40	38	<	62	55	59	<	73	67	73
	$\geq$	41	39	40	$\geq$	18	24	19	$\geq$	7	12	5
TS			.076				1.407				3.576	
REJECT H_0?/P			NO				NO				NO	

3. Statistical Tests in Support of Secondary Objectives

a. MOS Differences

(1) Probability of Detection (MOE #1)
(Refer to Table XX)

TEST: DIFFERENCE OF PROPORTIONS [Ref. 3 : p. 552-554]

H_0: $P_i = P_j$; $\forall i \neq j$

H_1: $P_i \neq P_j$; $\forall i \neq j$

TEST STATISTIC: $\dfrac{P_i - P_j}{\hat{\sigma}}$

REJECTION REGION: Reject H_0 if TS > $+Z_{\alpha/2}$

or TS < $-Z_{\alpha/2}$

TEST RESULTS:

H_0	RR	TS	REJECT H_0?/P
$P_{CHAP} = P_{VUL}$	$-1.96 > Z > +1.96$ (2 sided)	.934	NO
$P_{VUL} = P_{RED}$	$-1.28 > Z > +1.28$ (1 sided)	-1.78	YES/P < .05
$P_{CHAP} = P_{RED}$	$-1.28 > Z > +1.28$ (1 sided)	-1.56	YES/P < .1

(2) Time to Detection (MOE #2)
(Refer to Table XX and XXI)

TEST: 1-SIDED k-SAMPLE SMIRNOV TEST
[Ref. 5: p. 379-382]

H_0: $F_{RED} = F_{CHAP} = F_{VUL}$

H_1: $F_{RED} > F_{CHAP}$ and/or $F_{RED} > F_{VUL}$

TEST STATISTIC: $TS = \sup_{x, i<k} |s_i(x) - x_{i+1}(x)|$

REJECTION REGION: Reject H_0 if $TS > W_{1-\alpha}$ of of Table A23.

TEST RESULTS:

$S_i(x) - S_{i+1}(x)$	SMIRNOV TS
$S_{RED} - S_{CHAP}$	.218
$S_{RED} - S_{VUL}$	.132
$S_{CHAP} - S_{VUL}$	.202

$\sup |s_i(x) - s_{i+1}(x)| = .218$ REJECT $H_0/P < .05$

RR = .215

b. Age and Experience Differences

Categories selected:

	1	2
AGE:	$\leq$20 years	>20 years
EXPERIENCE:	$\leq$2 years	>2 years

(1) Probability of Detection (Refer to Table XXII)

TEST: DIFFERENCE OF PROPORTIONS [Ref. 3 : p. 552-554]

H_0: $P_1 = P_2$ for age, then experience

H_1: $P_1 \neq P_2$ for age, then experience

TEST STATISTIC: same as 3a.(1)

REJECTION REGION: same as 3a.(1)

TEST RESULTS: No significant differences in age or experience

(2) Time to Detection

TEST: 2-SIDED SMIRNOV TEST [Ref. 5 p. 369-373]

H_0: $F_1 = F_2$ for age, then experience

H_1: $F_1 \neq F_2$ for age, then experience

TEST STATISTIC: $TS = \sup_x |s_1(x) - s_2(x)|$

REJECTION REGION: Reject H_0 if $TS > W_{1-\alpha}$ of Table A21

TEST RESULTS

(a) <u>AGE</u>

	RED	VUL	CHAP	COMPOSITE
n	47	33	38	118
m	35	42	40	117
$\sup \lvert s_1(x) - s_2(x) \rvert$	.184	.195	.099	.109
RR	.272	.284	.276	.159
REJECT H_0?	NO	NO	NO	NO

(b) <u>EXPERIENCE</u>

n	58	36	38	132
m	24	39	40	103
$\sup \lvert s_1(x) - s_2(x) \rvert$	.234	.240	.025	.081
RR	.330	.310	.308	.178
REJECT H_0?	NO	NO	NO	NO

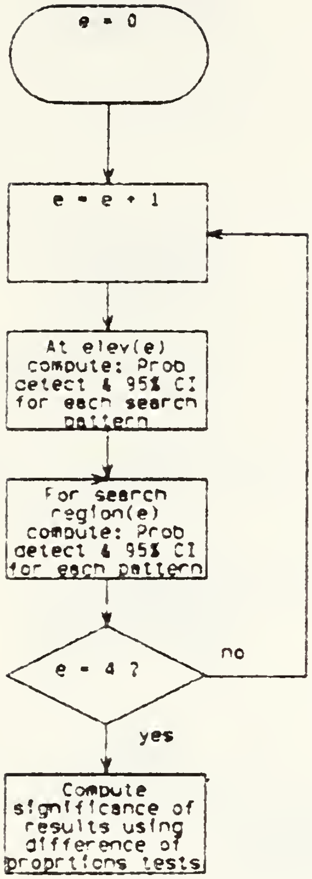
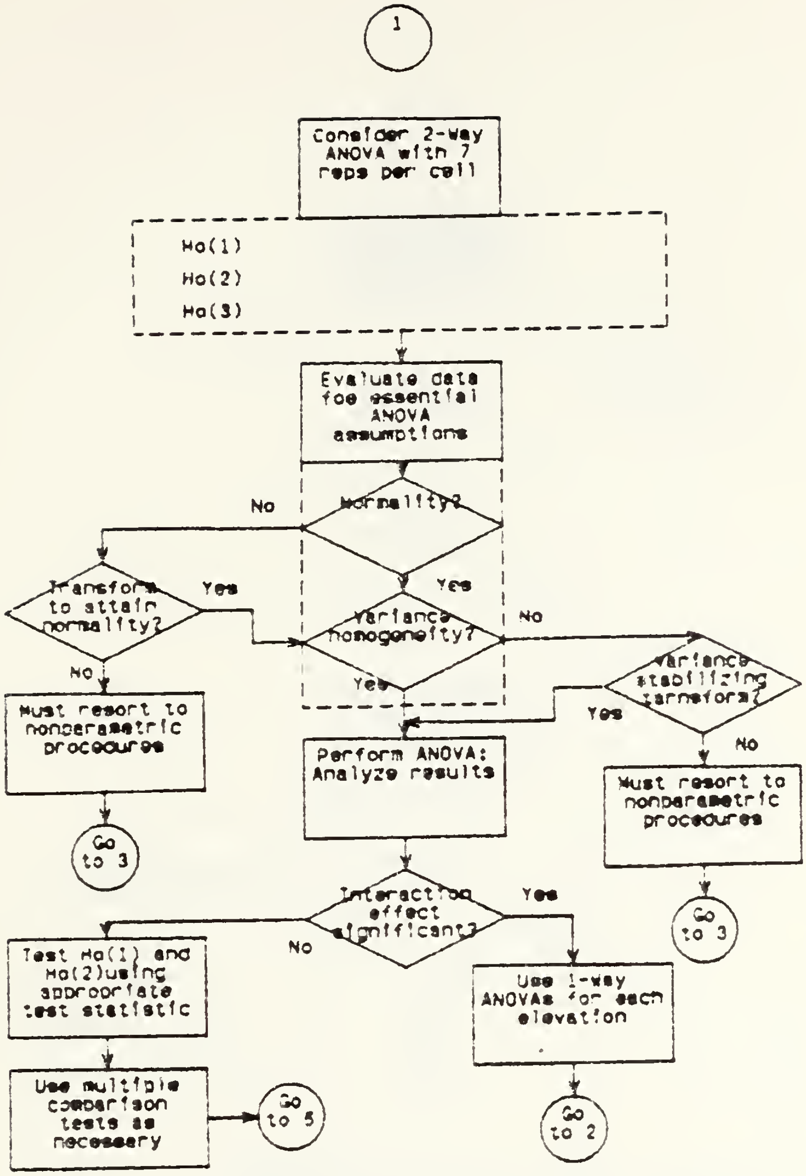


Figure D-1. Statistical Analysis Logic: MOE #1

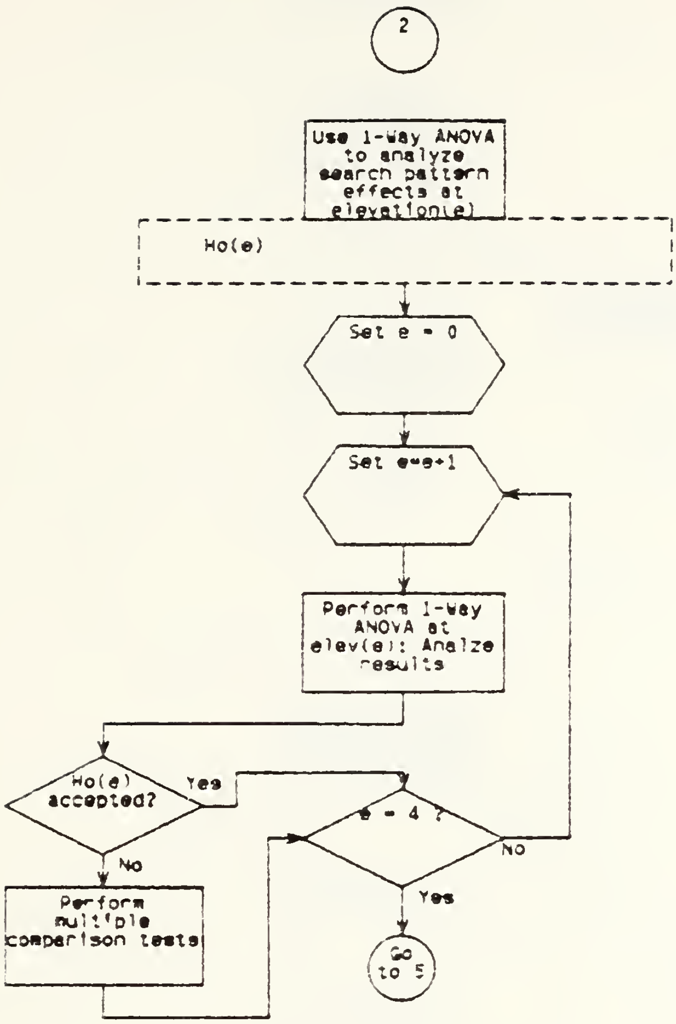


$H_o(1)$ - All search pattern mean times are the same

$H_o(2)$ - All elevation angle mean times are the same

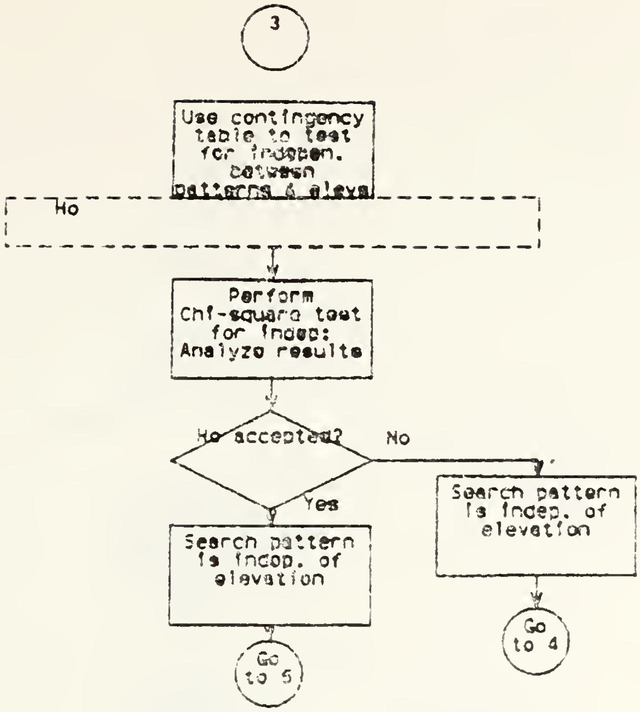
$H_o(3)$ - There is no significant interaction between search pattern and elevation angle

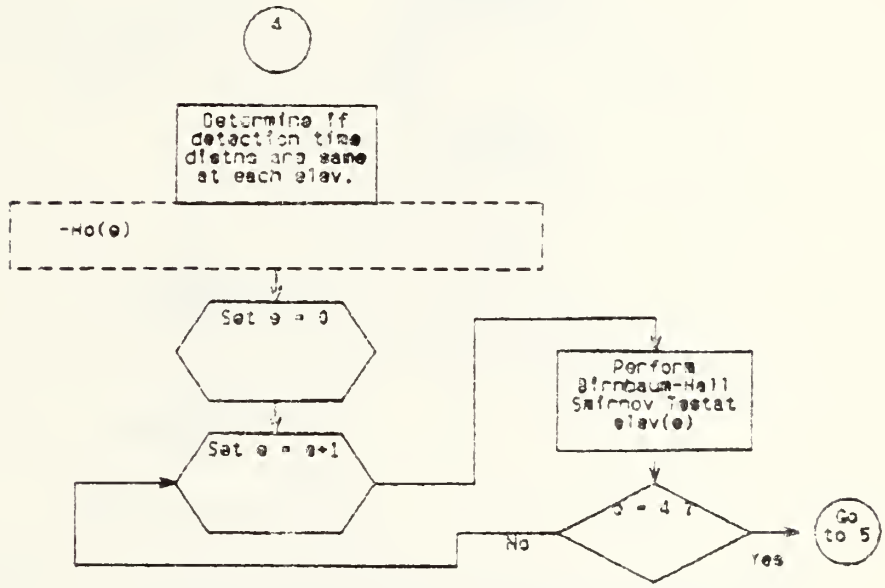
Figure D-2. Statistical Analysis Logic: MOE #2



$H_o(e)$ - Search pattern means are the same at elevation (e)

Figure D-3. Statistical Analysis Logic: MOE #2 (cont'd)

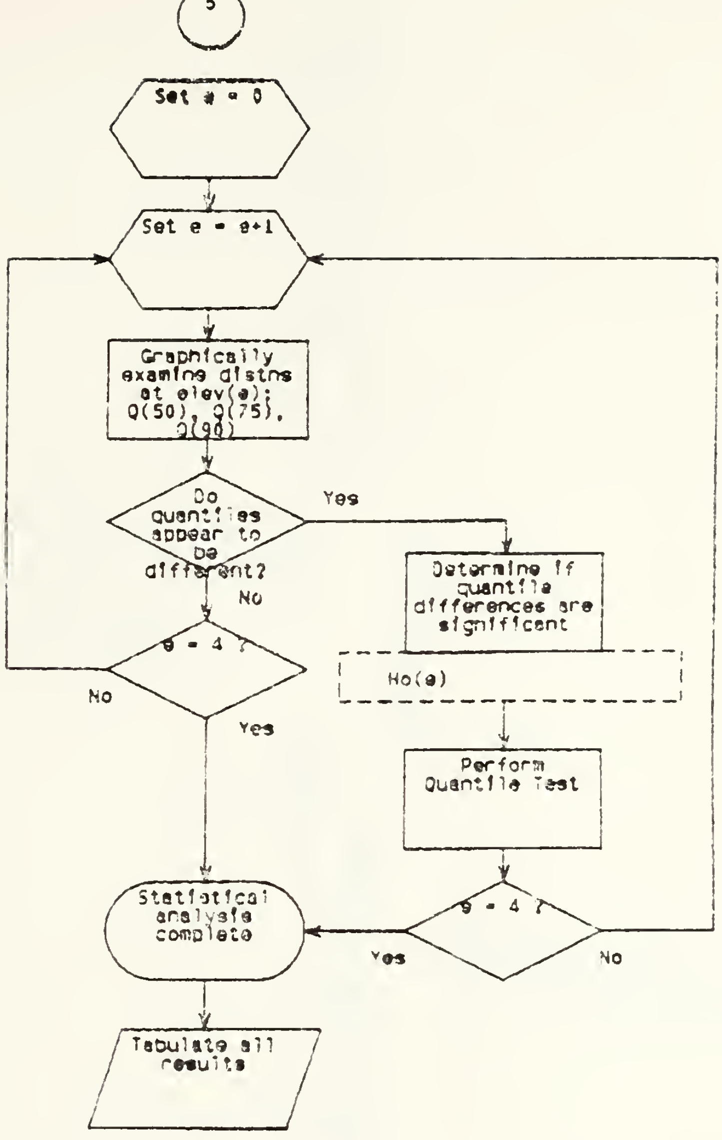




H_o - Search pattern type is independent of target elevation angle

$H_o(e)$ - Detection time distributions are the same for each search pattern at elevation (e)

Figure D-4. Statistical Analysis Logic: MOE #2 (cont'd)

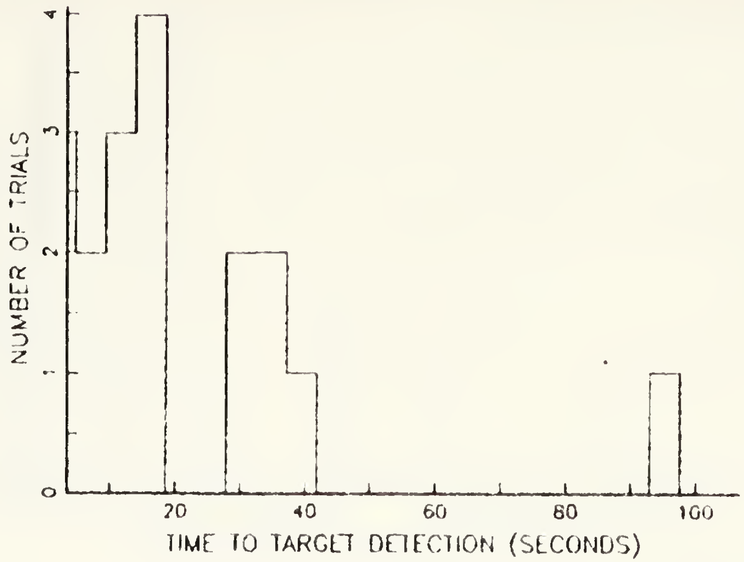


$H_o(e)$ - Specified quantiles are the same for all search patterns at elevation (e)

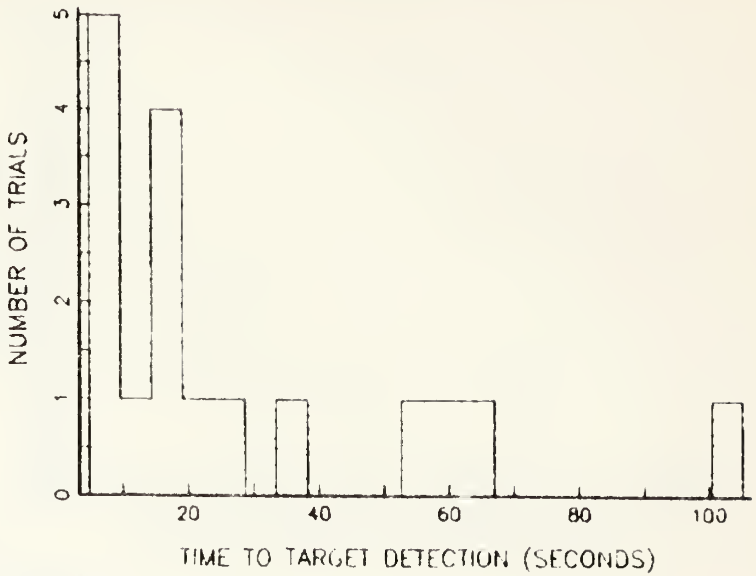
Figure D-5. Statistical Analysis Logic: MOE #2 (cont'd)

TABLE XXVI: SEARCH PATTERN HISTOGRAMS: <1 DEGREE

LATERAL SEARCH



VERTICAL SEARCH



HORIZON SEARCH

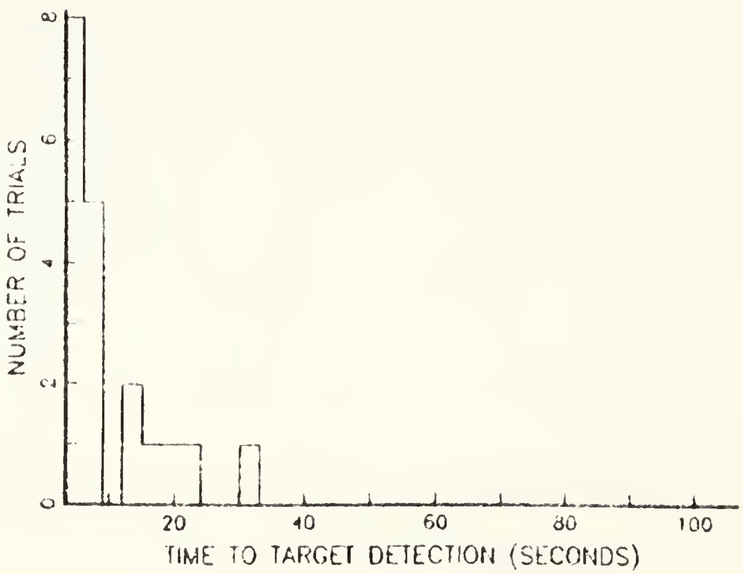
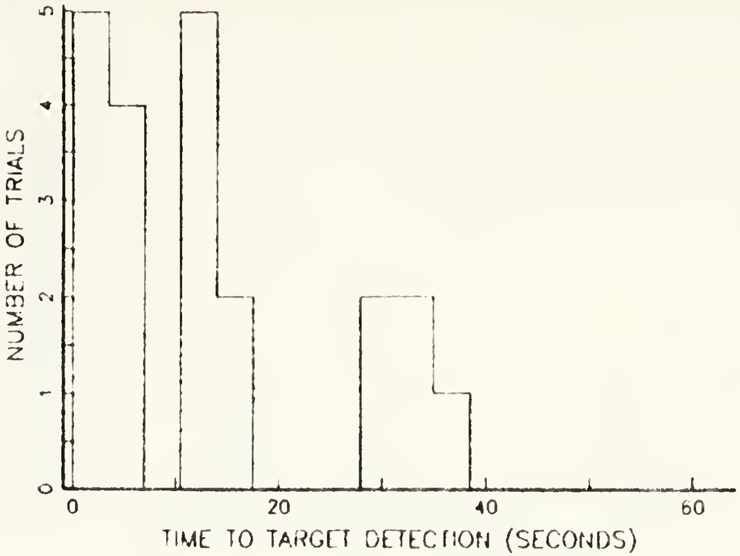
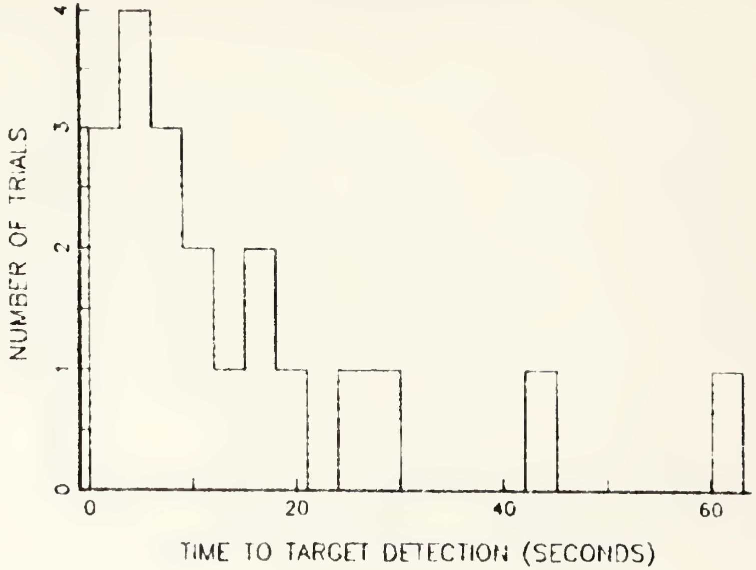


TABLE XXVII: SEARCH PATTERN HISTOGRAMS: 5 DEGREES

LATERAL SEARCH



VERTICAL SEARCH



HORIZON SEARCH

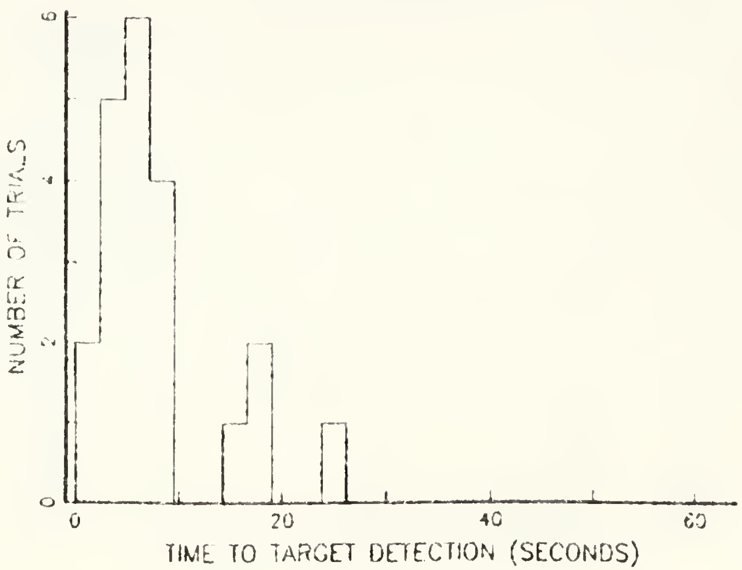
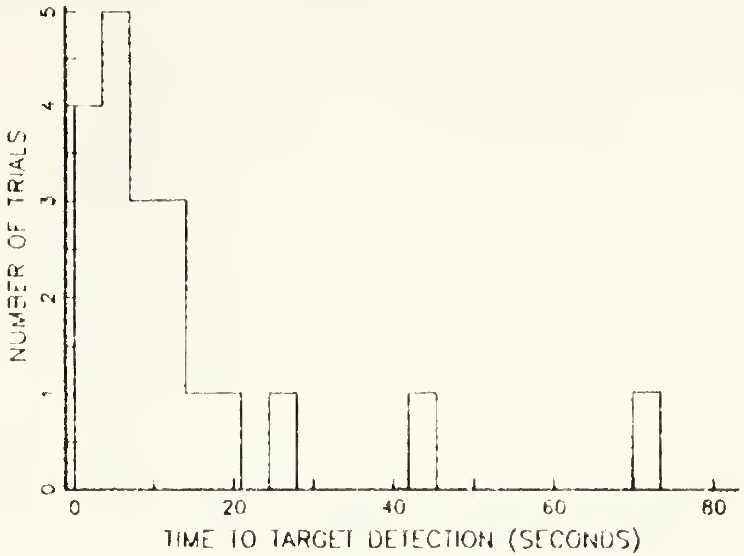
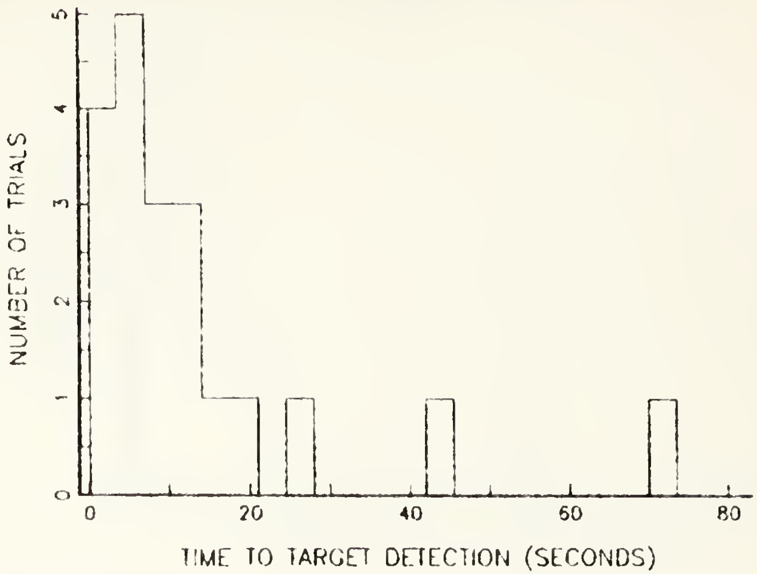


TABLE XXVIII: SEARCH PATTERN HISTOGRAMS: 15 DEGREES

LATERAL SEARCH



VERTICAL SEARCH



HORIZON SEARCH

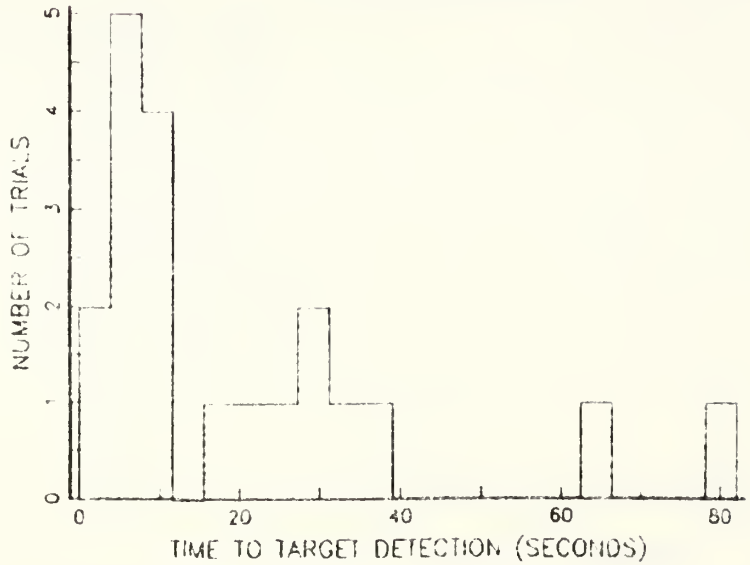


TABLE XXIX: SEARCH PATTERN HISTOGRAMS: 25 DEGREES

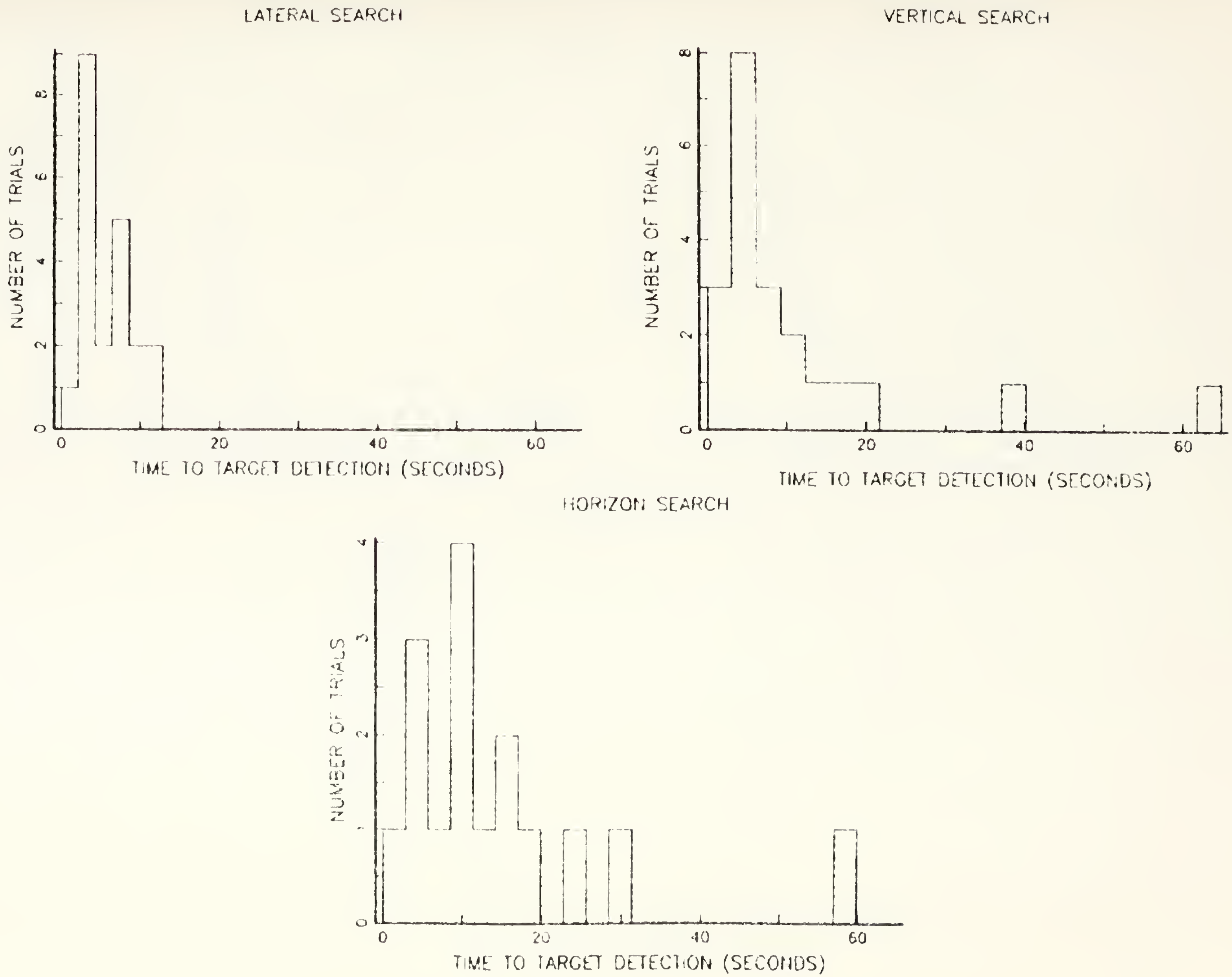
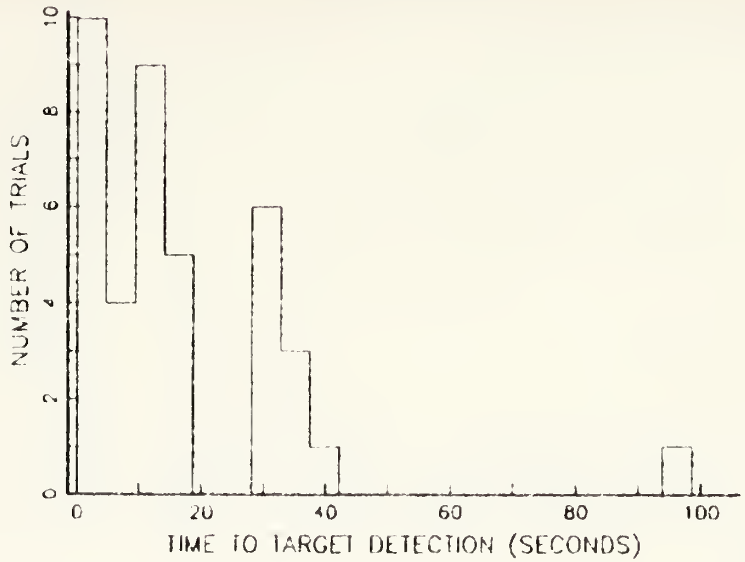
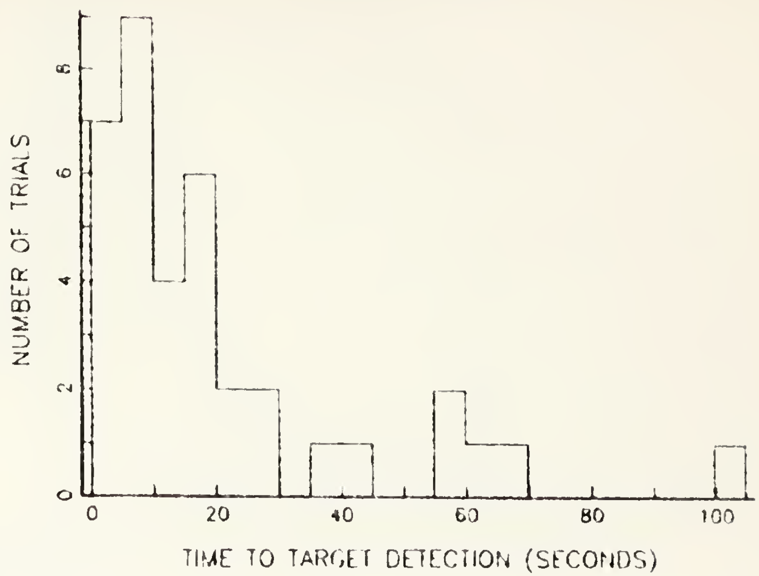


TABLE XXX: SEARCH PATTERN HISTOGRAMS: ≤5 DEGREES

LATERAL SEARCH



VERTICAL SEARCH



HORIZON SEARCH

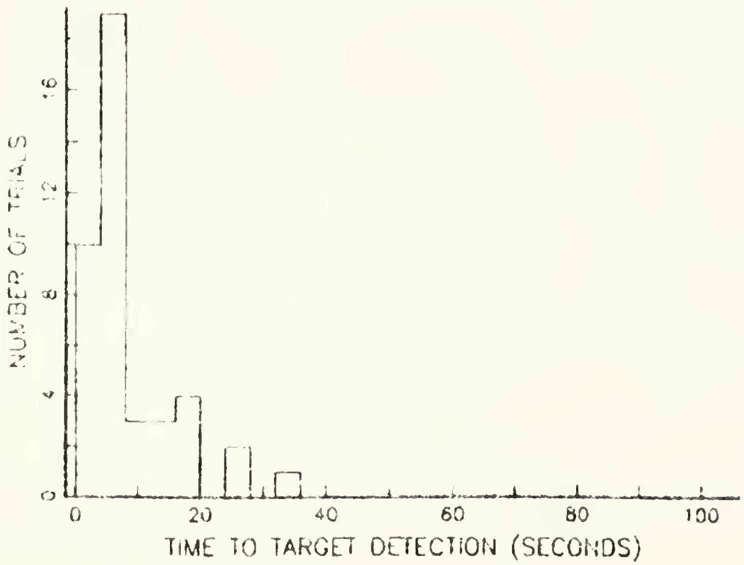
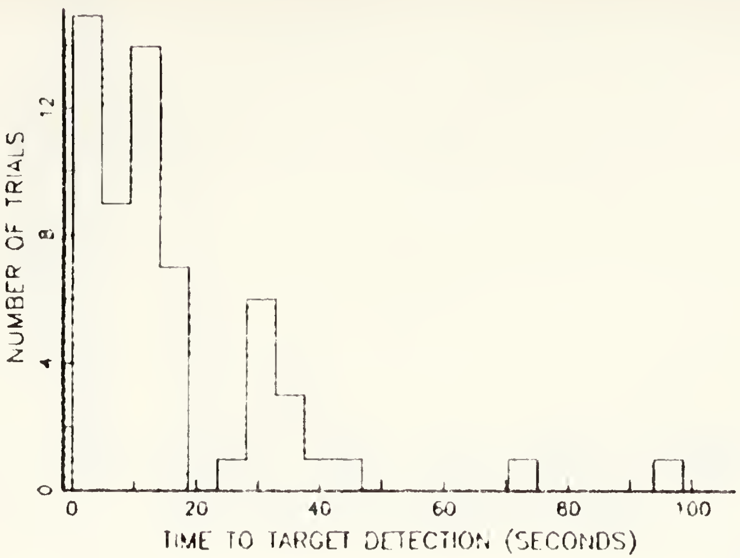
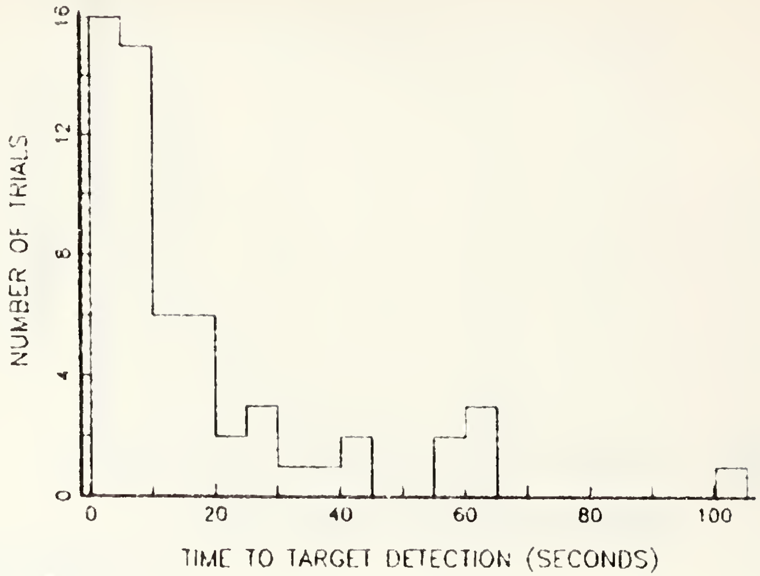


TABLE XXXI: SEARCH PATTERN HISTOGRAMS: ≤15 DEGREES

LATERAL SEARCH



VERTICAL SEARCH



HORIZON SEARCH

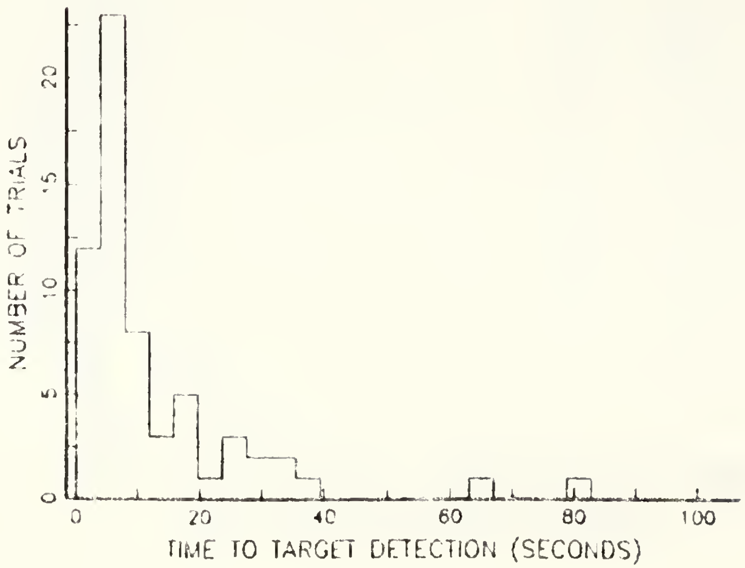
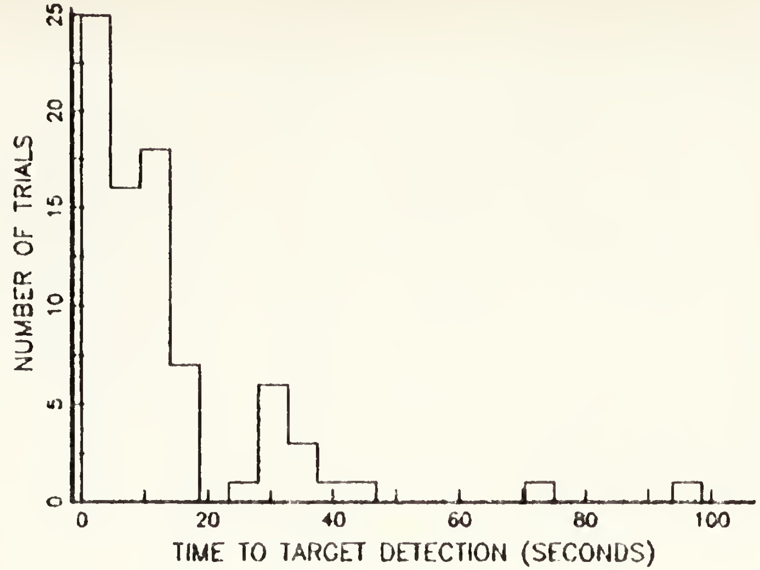
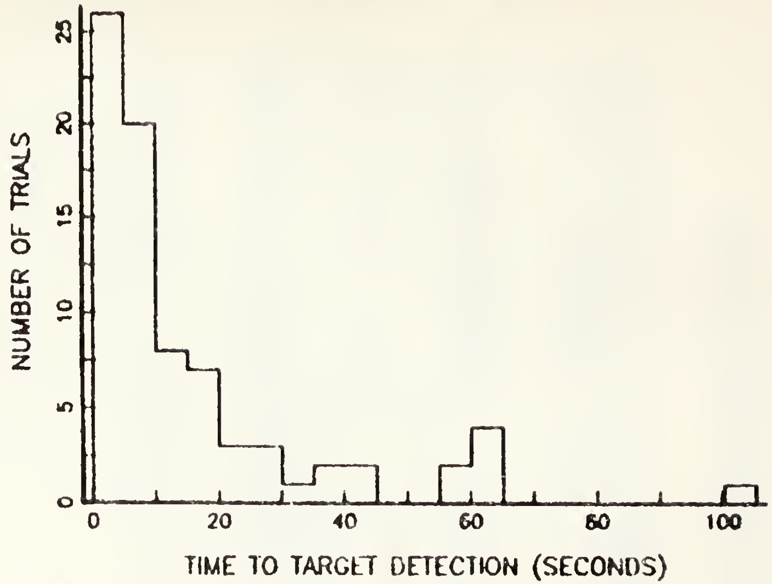


TABLE XXXII: SEARCH PATTERN HISTOGRAMS: ≤25 DEGREES

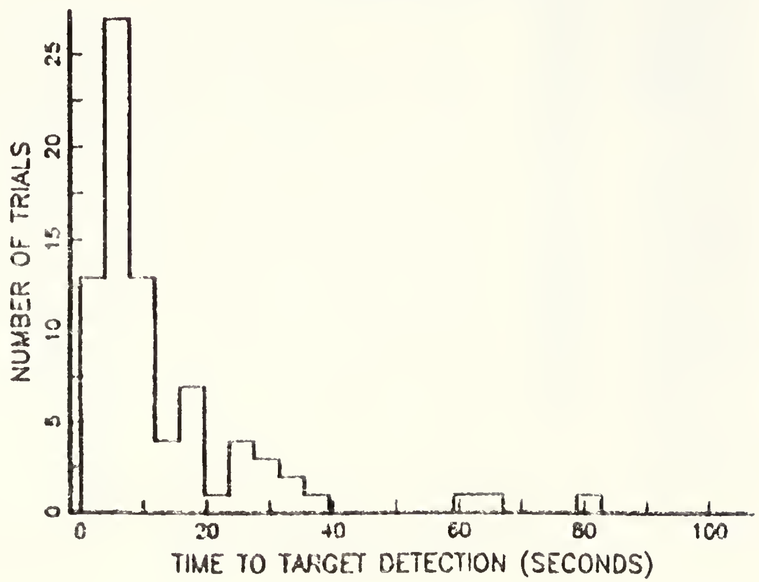
LATERAL SEARCH



VERTICAL SEARCH



HORIZON SEARCH



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Attn: Director
Ft. Bliss, TX 79916

14. Commandant 1
U.S. Army Air Defense School
Directorate of Training Developments
Attn: ATSA-DTI-SP (Mr. Porter)
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15. Commandant 1
U.S. Army Air Defense School
Directorate of Combat Developments
Attn: Director
Ft. Bliss, TX 79916

16. Commandant 1
U.S. Army Air Defense School
Department of Tactics
Attn: ATSA-DTT-D (Mr. C. Vaillancourt)
Ft. Bliss, TX 79916

17. Office of the Under Secretary of Defense 1
(Research and Engineering)
Joint Forward Area Air Defense Task Force
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Ft. Bliss, TX 79916

18. Commander 1
7th Infantry Division
Attn: G-3
Ft. Ord, CA 93940

19. Commander 1
1st Battalion, 51st Air Defense Artillery
Attn: AFZW-AD
Ft. Ord, CA 93940

20. Systems Engineering Test Directorate 1
Naval Air Test Center
Attn: CDR William F. Moroney
Patuxent River, MD 20670

21. Commander 1
U.S. Army Missile Command, Redstone Arsenal
Attn: DRSMI-RDW (Mr. A.C. Poe)
Bldg. 5400
Huntsville, AL 35898

22. Commander 1
U.S. Army MIssile Command, Restone Arsenal
Attn: DRCPM-MPE (Mr. K. Burque)
Huntsville, AL 35809

23. Department of Engineering 2
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